AutoCSP: Automatically Retrofitting CSP to Web Applications

Mattia Fazzini, Prateek Saxena, Alessandro Orso

Georgia Tech

NUS National University of Singapore

Georgia Tech

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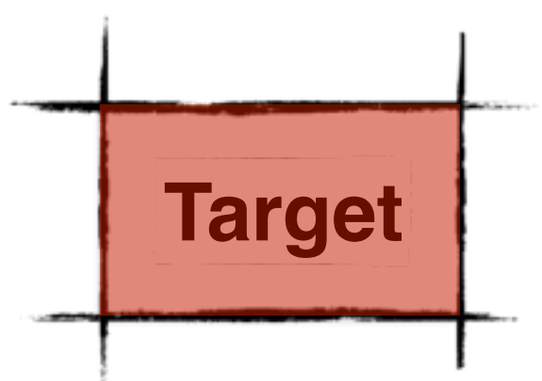
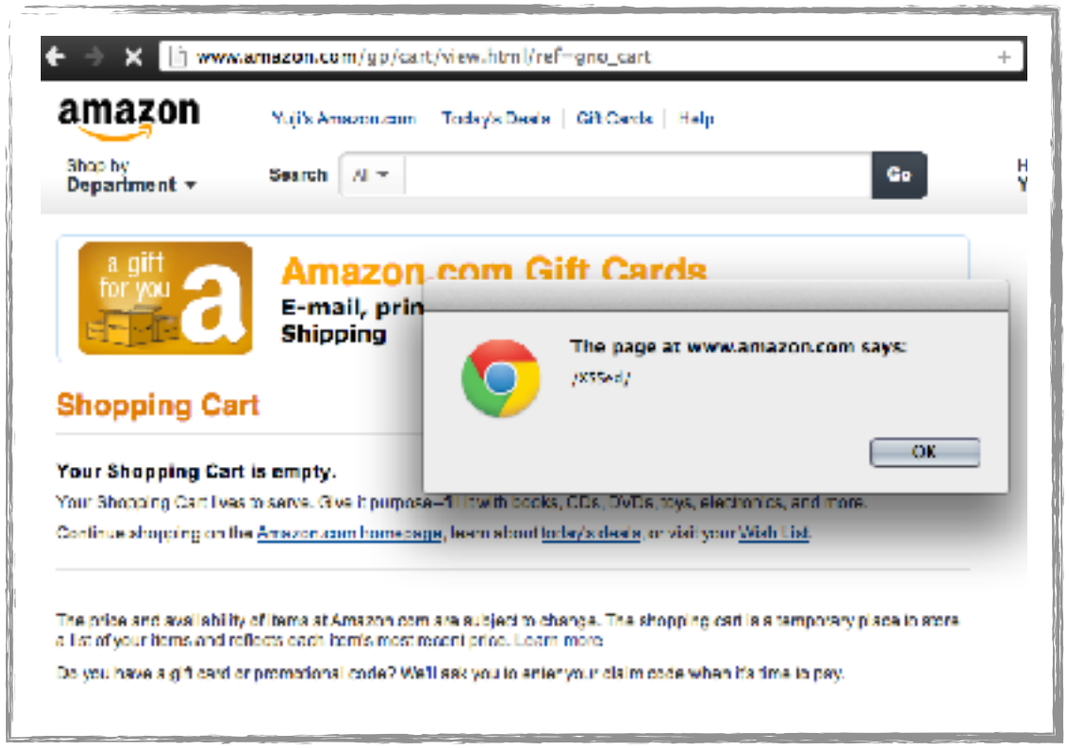


Cross-Site Scripting (XSS)



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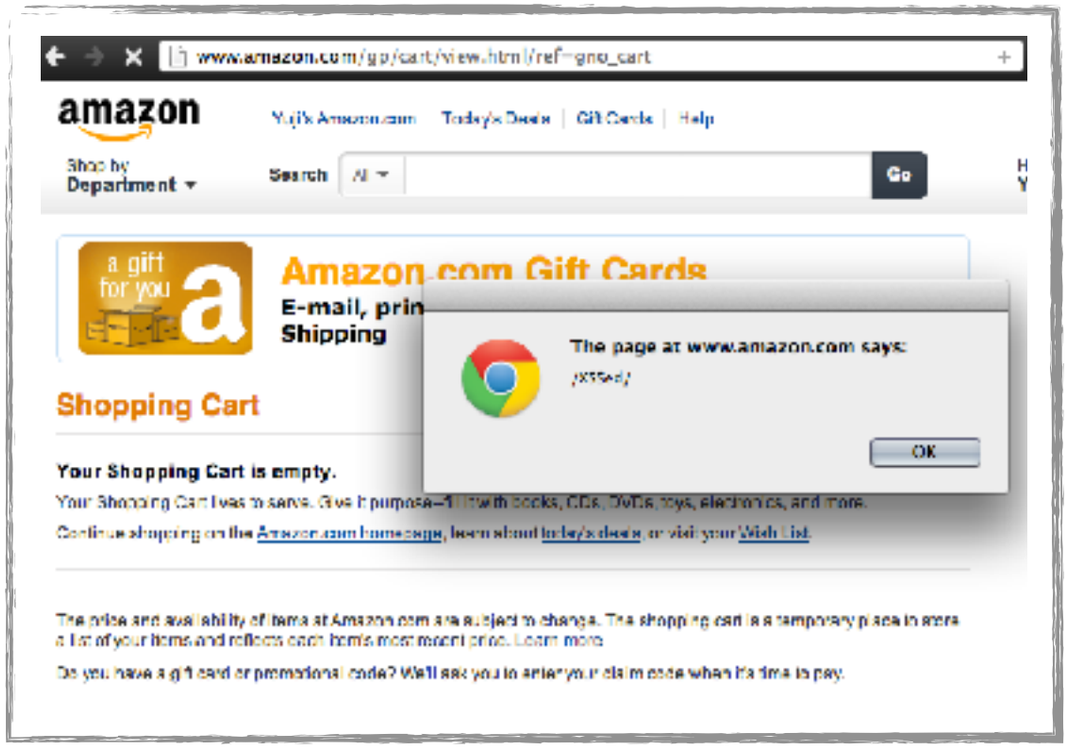
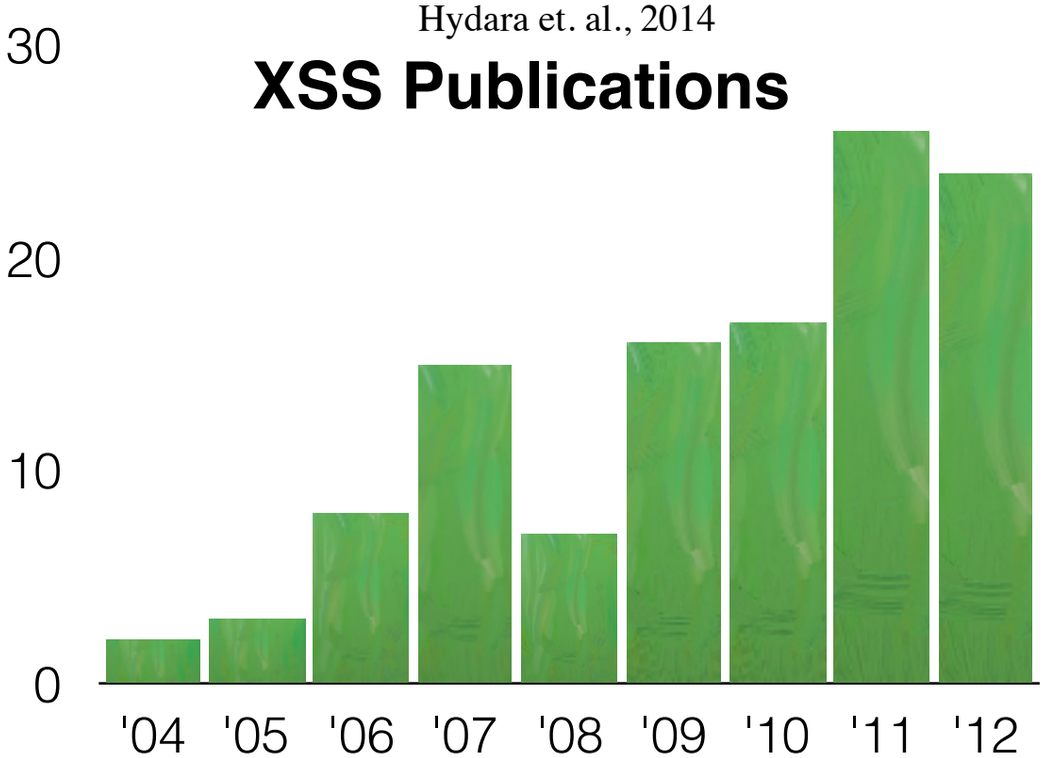


Hydara et. al., 2014



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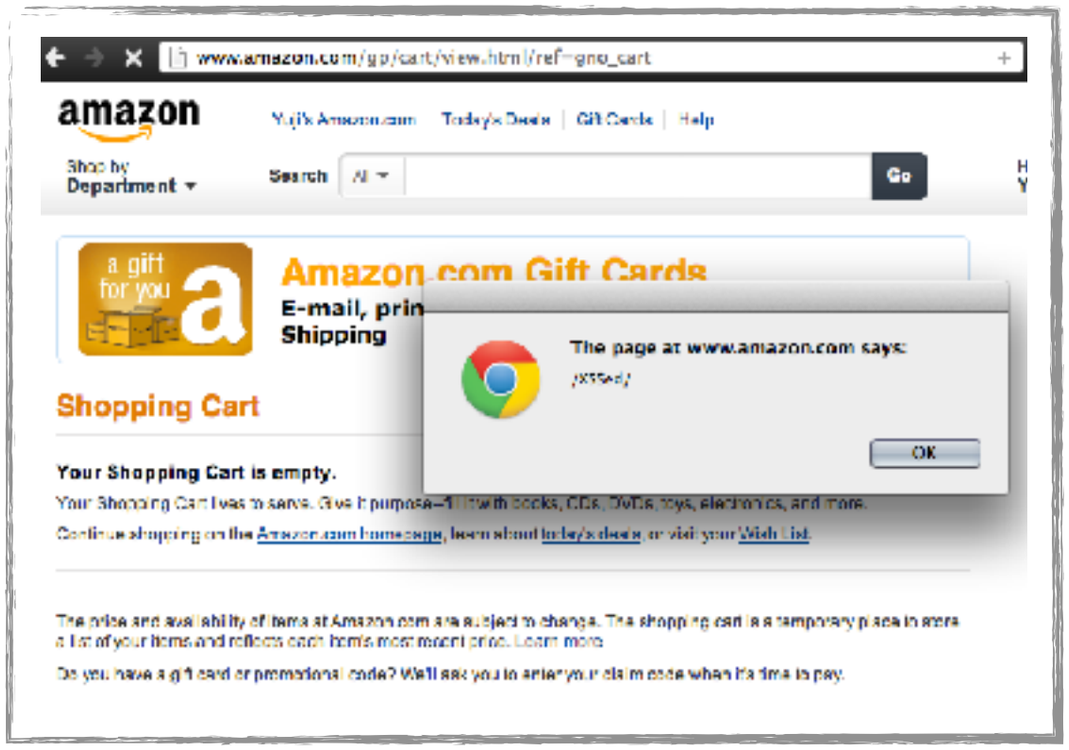

18 Sep 2014

"eBay Under Fire After Cross Site Scripting Attack"

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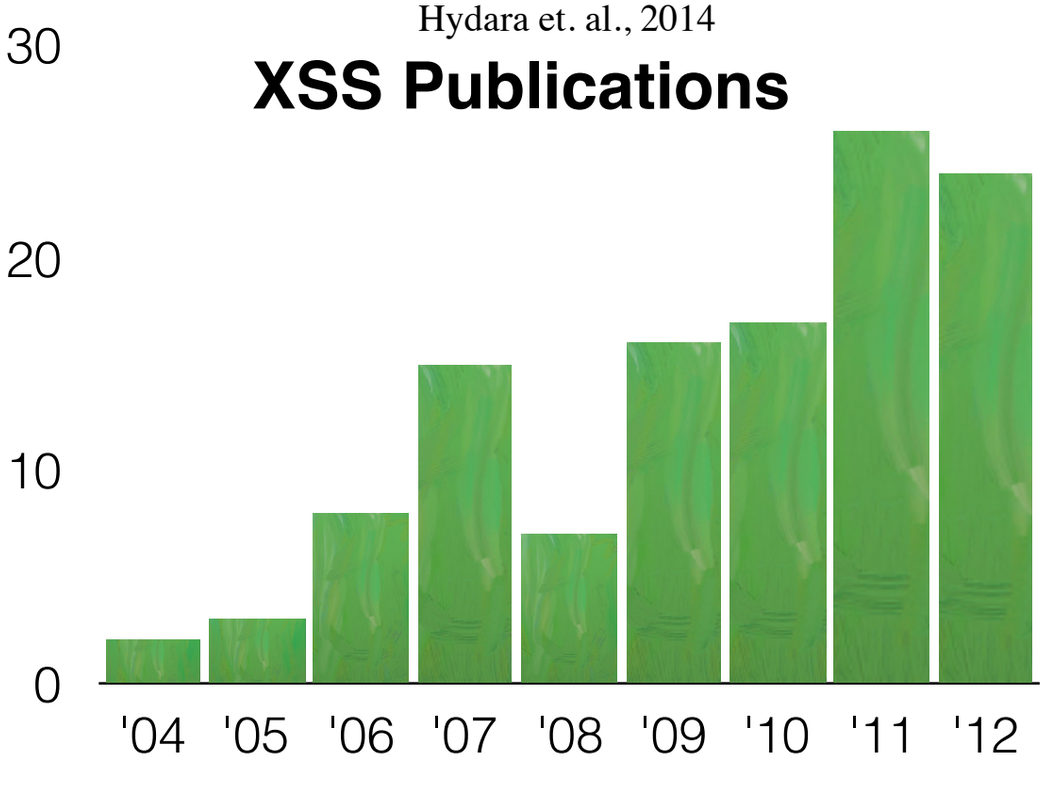

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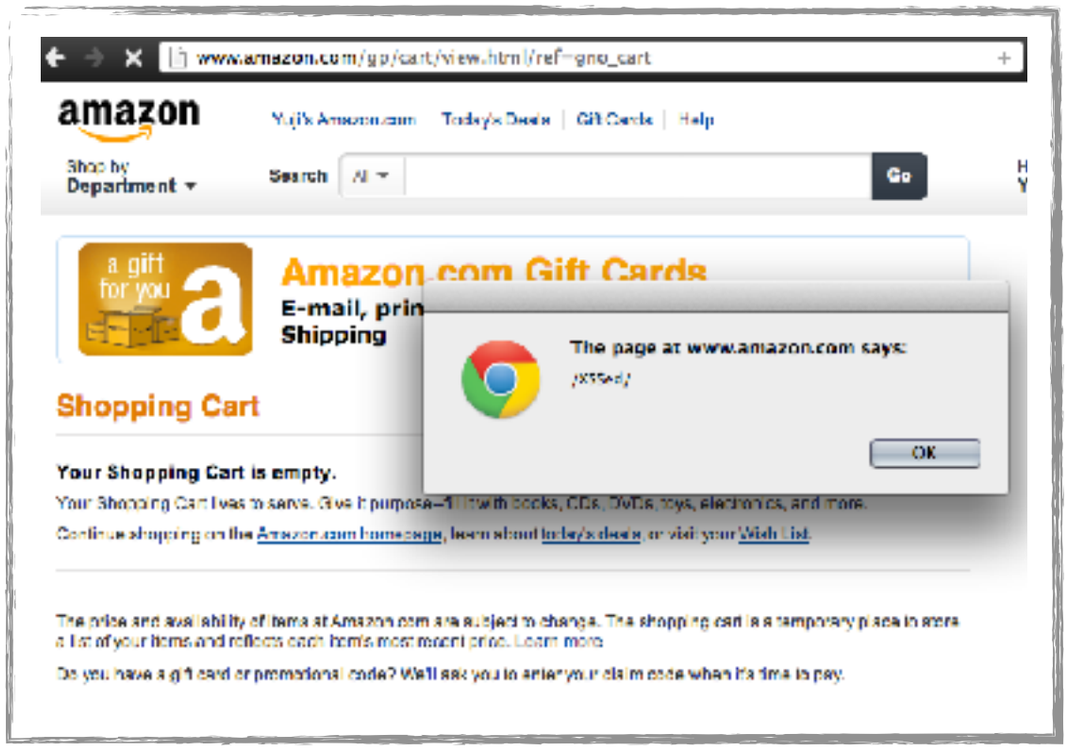

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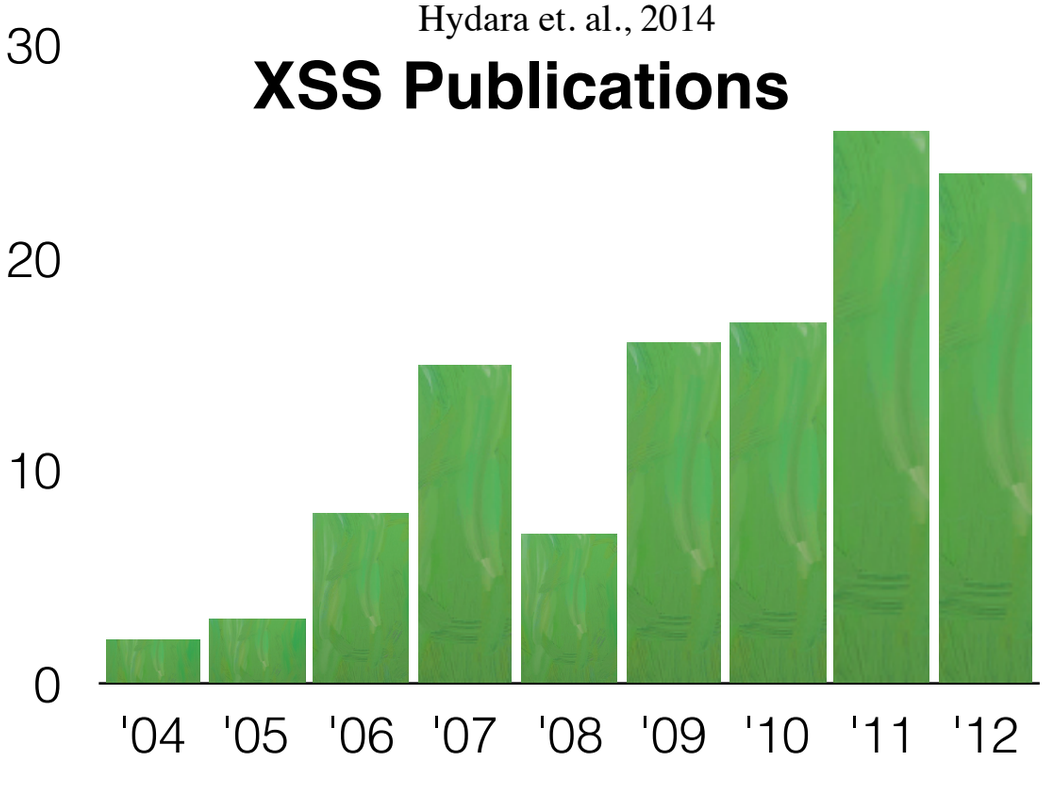
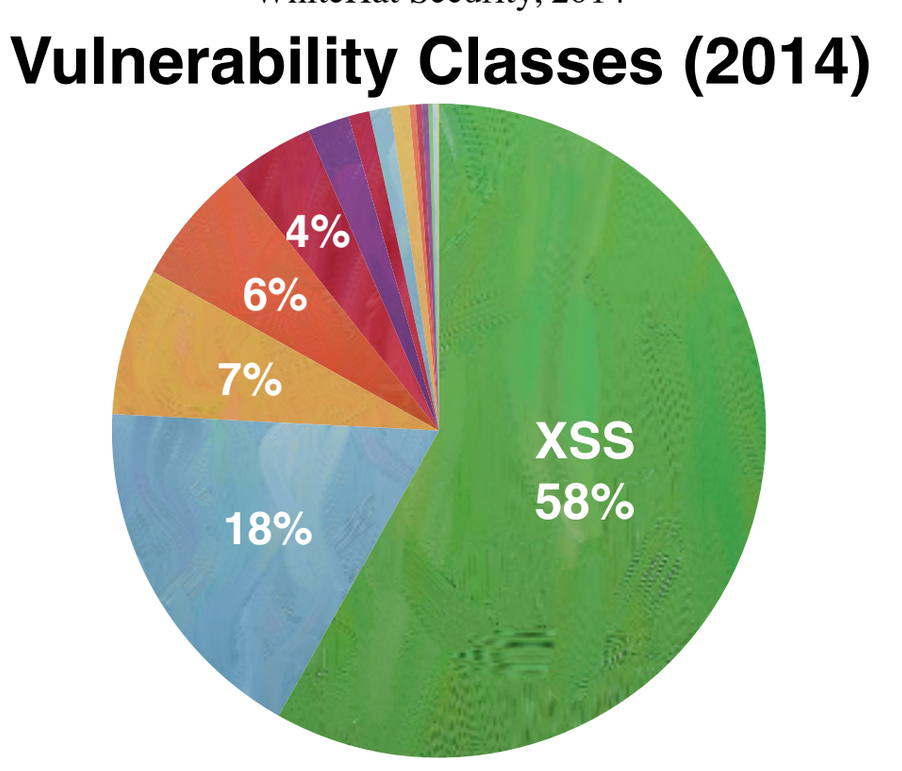
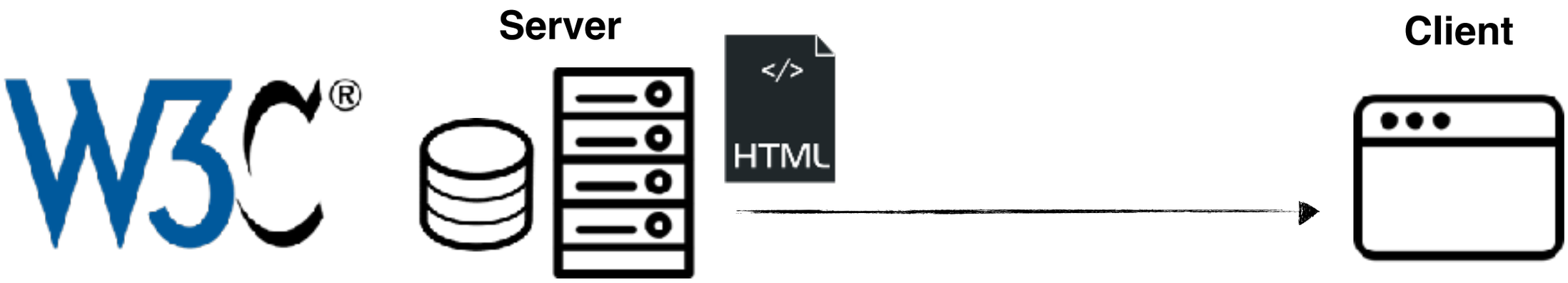


WhiteHat Security, 2014



Content Security Policy (CSP)



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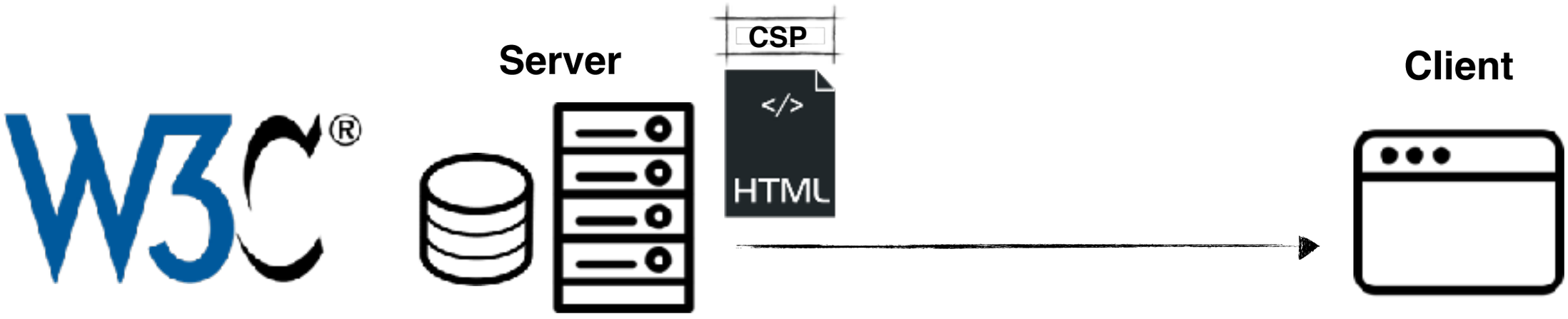

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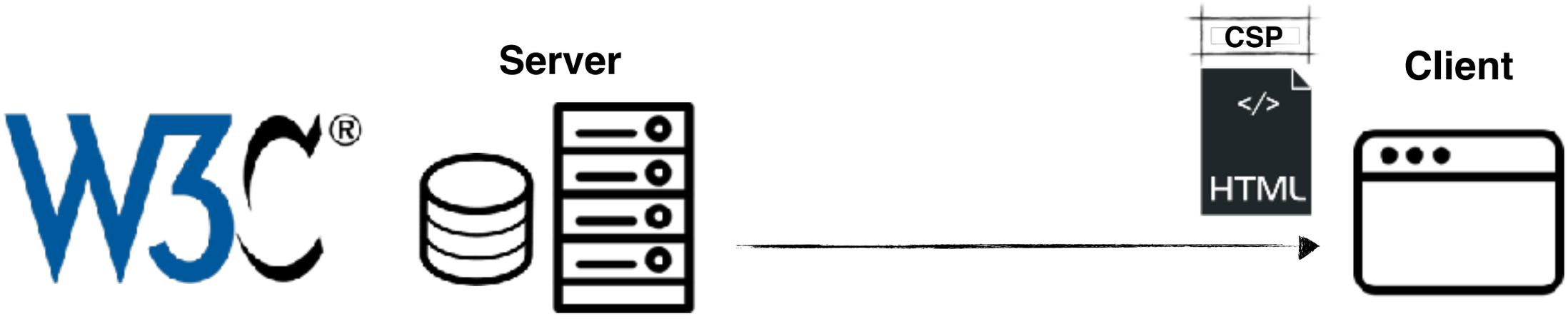

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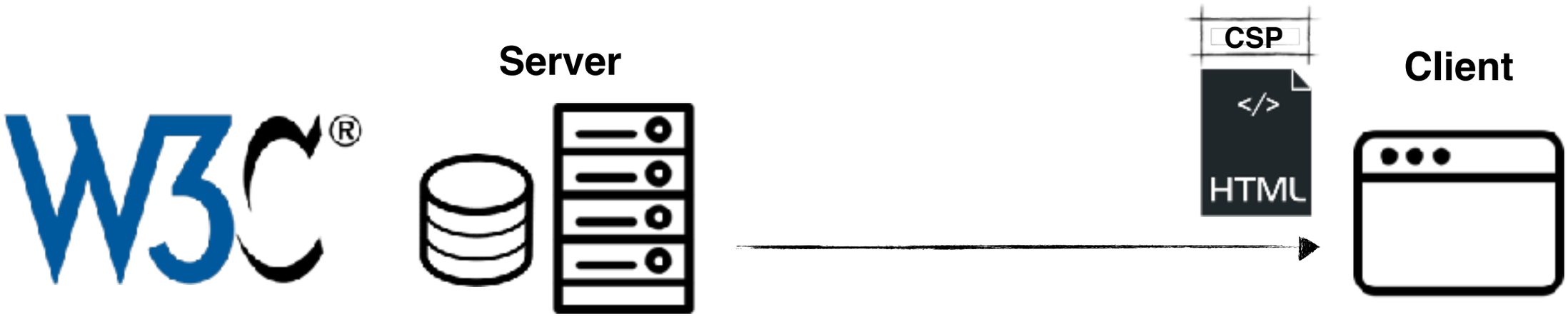

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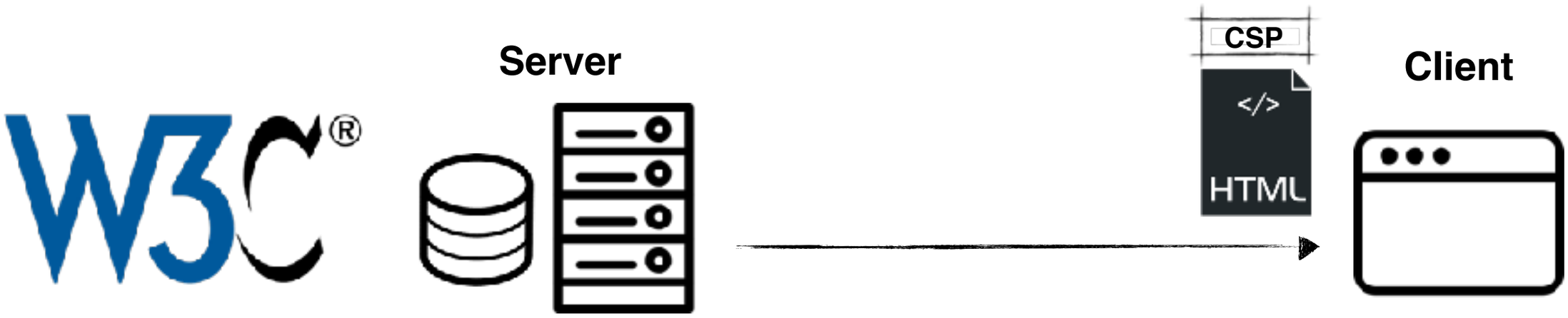

Name Content-Security-Policy

Directives script-src | style-src | img-src | frame-src | …

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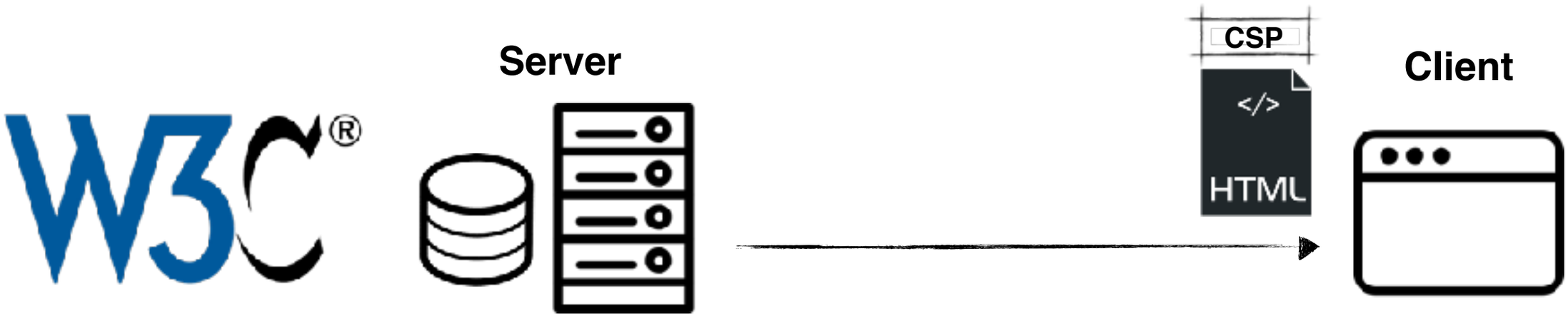

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Directives	script-src, style-src, img-src, frame-src, …
Values	‘none’ , ‘self’, domain, ‘unsafe-inline’, ‘unsafe-eval’

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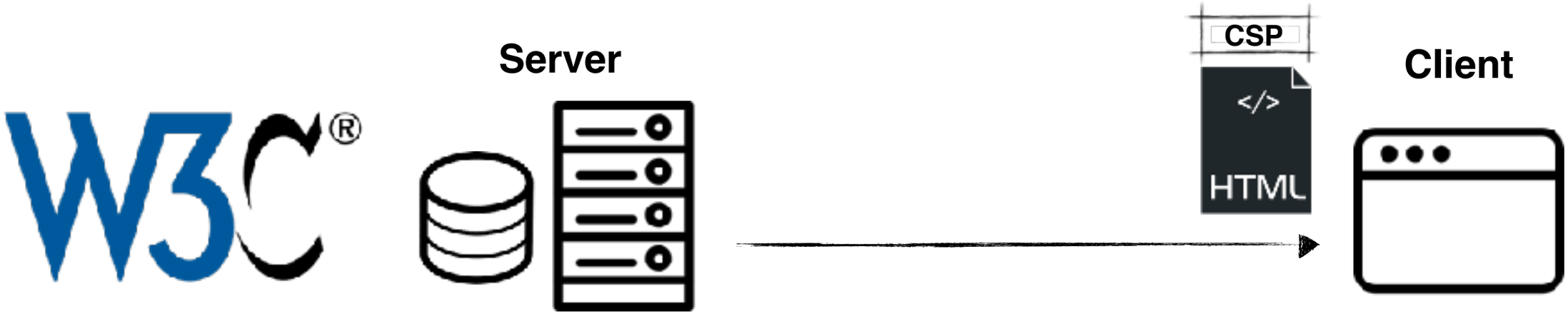

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v13	v42	v47	v9	v33

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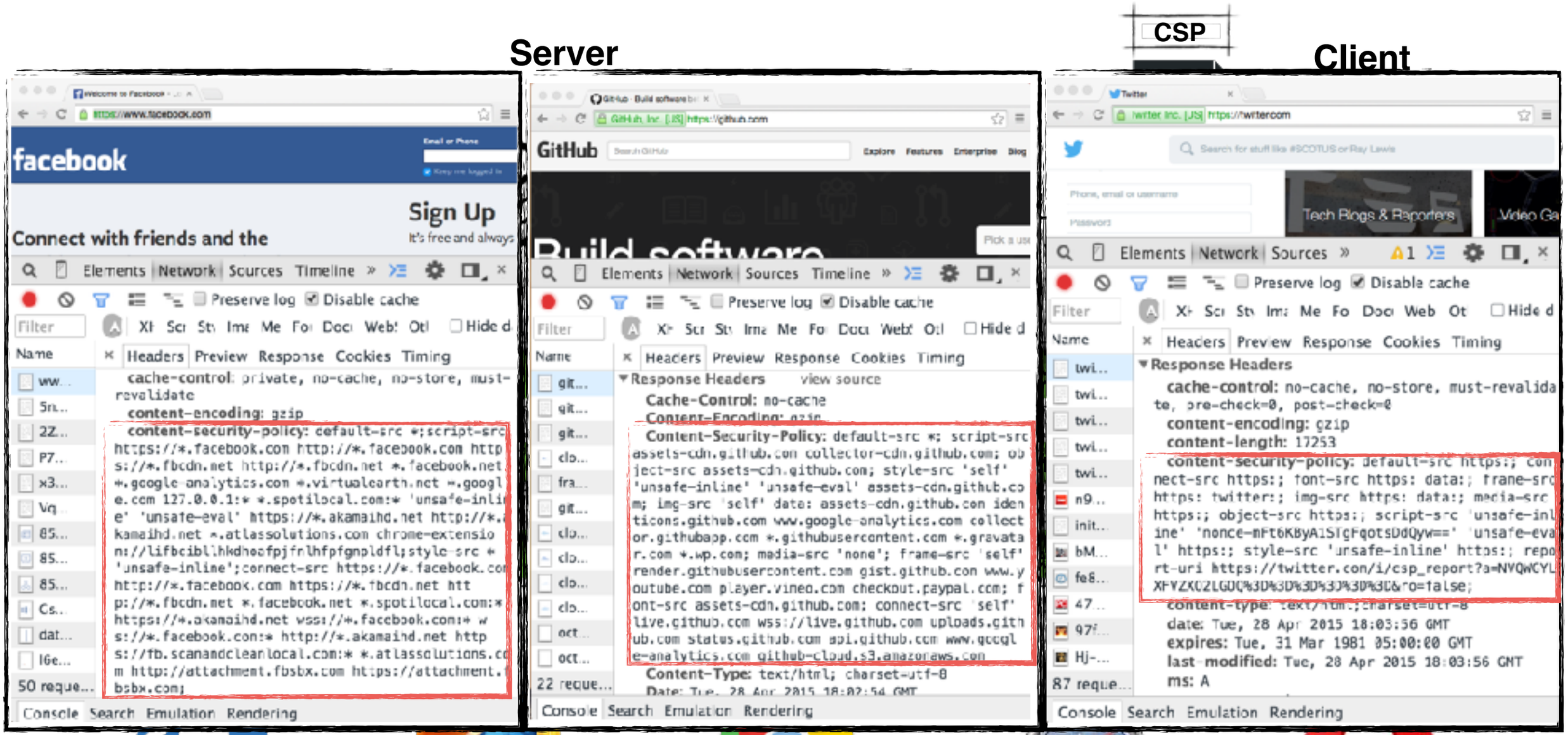

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Motivating Example

Server-side Code

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10 print($out);
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16 while($assignment =
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Web Page

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18   ...
19   <td style='text-align: left;'>
20    <script>alert('XSS');</script>
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```

Hardcoded inline script

Hardcoded JS scheme

Hardcoded inline attribute

Motivating Example

Server-side Code

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2 ...
3 $out="<script>
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Web Page

Inline script from persistent XSS

```
1 <html>
2  <head>
3  ...
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5  <body>
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Content-Security-Policy:
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24 print("</html>"); ?>
```

Content-Security-Policy:
script-src: ‘unsafe-inline’
style-src: ‘unsafe-inline’

Web Page

```
1 <html>
2  <head>
3  ...
4  </head>
5  <body>
6   ...
7   <script>
8    function grades(){
9      document.student.page2.value=3;
10     document.student.submit();
11   }
12  </script>
13  ...
14  <a
15   href='javascript:grades();'>
16   Grades
17  </a>
18  ...
19  <td style='text-align: left;'>
20   <script>alert(‘XSS');</script>
21  </td>
22  ...
23  </body>
24 </html>
```

Motivating Example

Server-side Code

```
1 <?php print("<html>\n <head>");
2 ...
3 $out="<script>
4  function grades(){
5    document.student.page2.value=3;
6    document.student.submit();
7  }
8  </script>"
9 ...
10 print($out);
11 ...
12 print("<a
13  href='javascript:grades();'>
14  Grades</a>");
15 ...
16 while($assignment =
17  mysql_fetch_row($query)){
18   ...
19   print("<td style='text-align:left;'>"
20    .$assignment[5].
21    "</td>");
22  ...
23  }
24 print("</html>"); ?>
```

Web Page

```
1 <html>
2  <head>
3  ...
4  </head>
5  <body>
6   ...
7   <script>
8    function grades(){
9        document.student.page2.value=3;
10       document.student.submit();
11   }
12  </script>
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15   href='javascript:grades();'>
16   Grades
17  </a>
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19  <td style='text-align: left;'>
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23 </body>
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Motivating Example

Server-side Code

```
1 <?php print("<html>\n <head>");
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23  }
24 print("</html>"); ?>
```

CSP-enabled Web Page

Motivating Example

Server-side Code

```
1 <?php print("<html>\n <head>");
2 ...
3 $out="<script>
4  function grades(){
5    document.student.page2.value=3;
6    document.student.submit();
7  }
8  </script>"
```

Content-Security-Policy:
script-src: ‘domain’
style-src: ‘domain’

```
15 ...
16 while($assignment =
17  mysql_fetch_row($query)){
18   ...
19   print("<td style='text-align:left;'>"
20    .$assignment[5].
21    "</td>");
22  ...
23  }
24 print("</html>"); ?>
```

CSP-enabled Web Page

```
1 <html>
2  <head>
3   ...
4   <script src='uri.js'>
5   </script>
6   <link rel='stylesheet'
7    type='css' href='style.css'/>
8   ...
9  </head>
10  <body>
11  ...
12  <script src='external.js'>
13  </script>
14  ...
15  <a id=‘uri’ href='#'>
16   Grades
17  </a>
18  ...
19  <td id='style'>
20   <script>alert('XSS');</script>
21  </td>
22  ...
23  </body>
24 </html>
```

Motivating Example

Server-side Code

```
1 <?php print("<html>\n <head>");
2 ...
3 $out="<script>
4  function grades(){
5    document.student.page2.value=3;
6    document.student.submit();
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8  </script>"
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Content-Security-Policy:
script-src: ‘domain’
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15 ...
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17  mysql_fetch_row($query)){
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CSP-enabled Web Page

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17  </a>
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19  <td id='style'>
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22  ...
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24 </html>
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Motivating Example

Server-side Code

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1 <?php print("<html>\n <head>");
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3 $out="<script>
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17  mysql_fetch_row($query)){
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Content-Security-Policy:
script-src: ‘domain’
style-src: ‘domain’

CSP-enabled Web Page

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1 <html>
2  <head>
3   ...
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5   </script>
6   <link rel='stylesheet'
7    type='css' href='style.css'/>
8   ...
9  </head>
10  <body>
11  ...
12  <script src='external.js'>
13  </script>
14  ...
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22  ...
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24 </html>
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Motivating Example

Server-side Code

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CSP-enabled Web Page

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16   Grades
17  </a>
18  ...
19  <td id='style'>
20   <script>alert('XSS');</script>
21  </td>
22  ...
23  </body>
24 </html>
```

Goal

Automatically change server-side code to generate CSP-enabled web pages

AutoCSP Overview

AutoCSP Overview

Inputs

Web App

AutoCSP Overview

Inputs

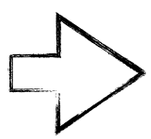
Web App

Transformed Web App

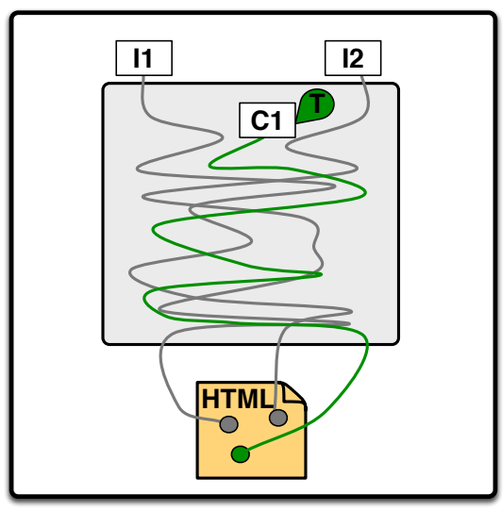
AutoCSP Overview

Inputs

Web App



Dynamic Tainting

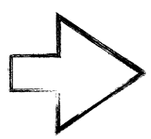


Transformed Web App

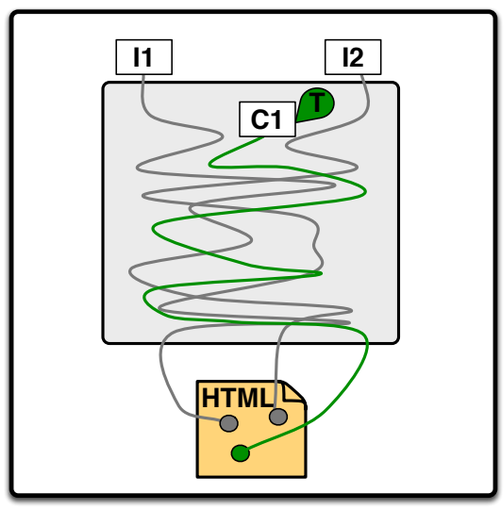
AutoCSP Overview

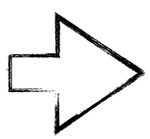
Inputs

Web App

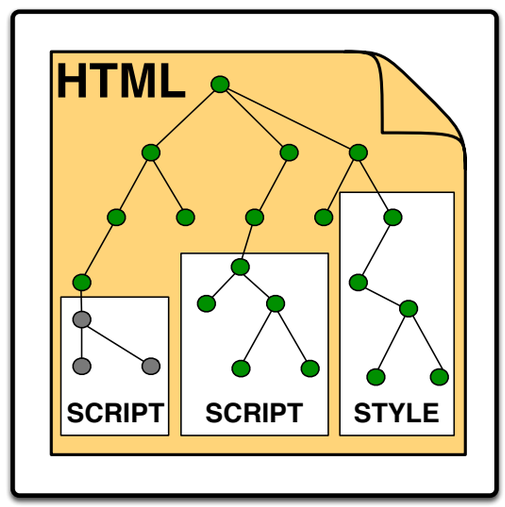


Dynamic Tainting





Web Page Analysis



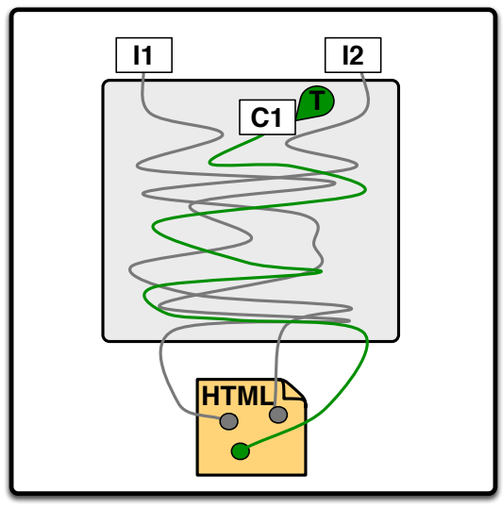
Transformed Web App

AutoCSP Overview

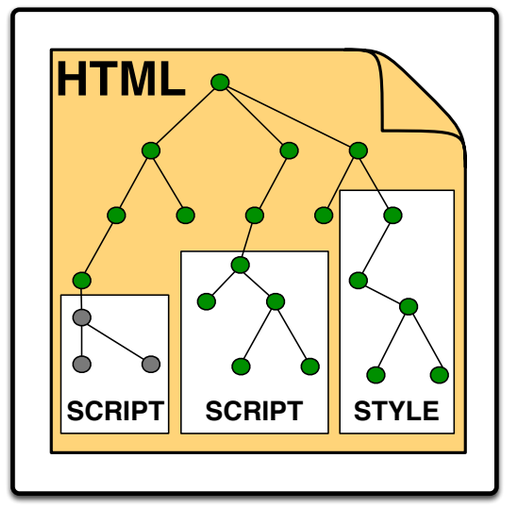
Inputs

Web App

Dynamic Tainting

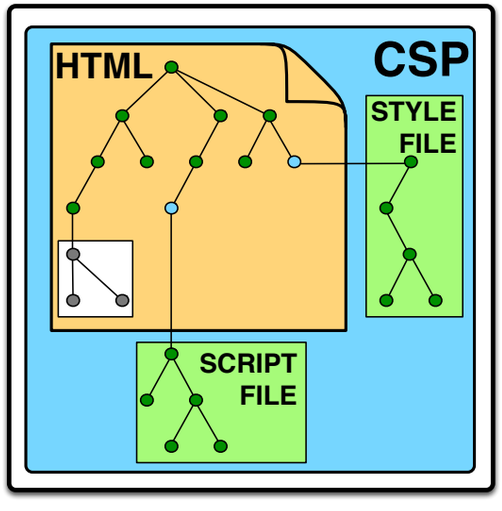


Web Page Analysis



Transformed Web App

CSP Analysis

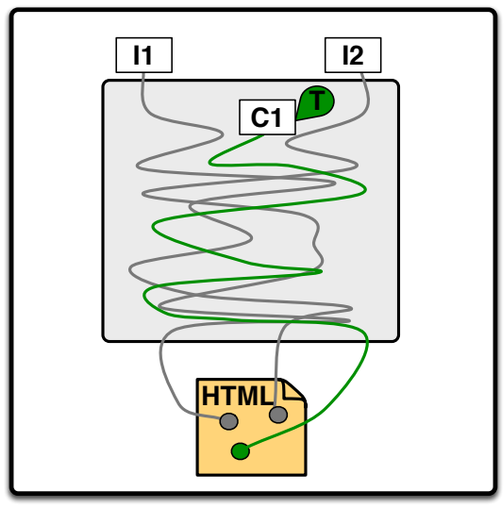


AutoCSP Overview

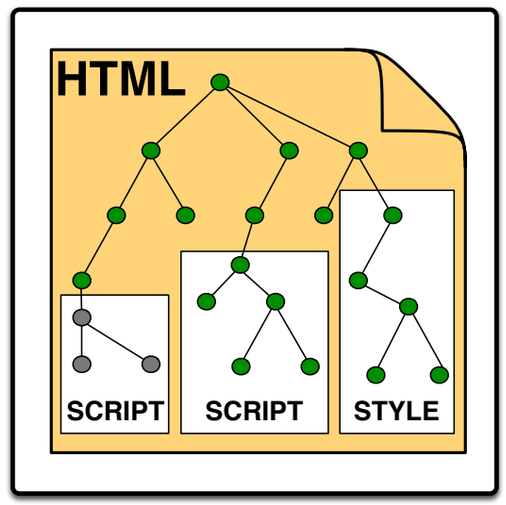
Inputs

Web App

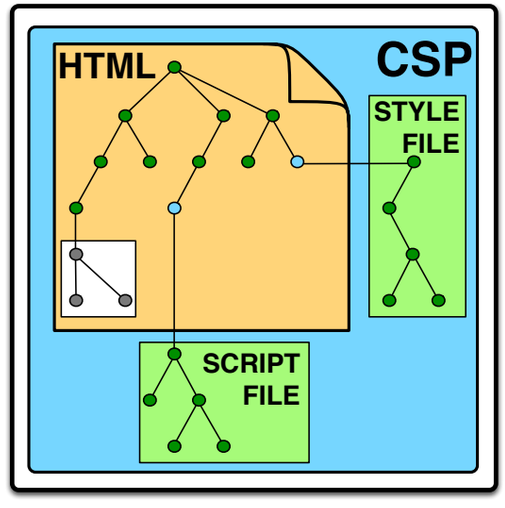
Dynamic Tainting



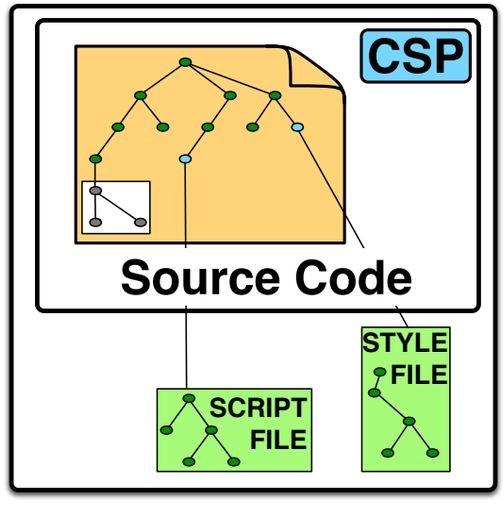
Web Page Analysis



CSP Analysis



Source Code Transformation



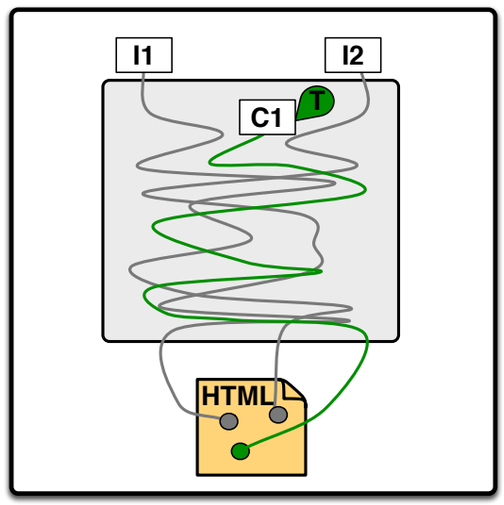
Transformed Web App

AutoCSP Overview

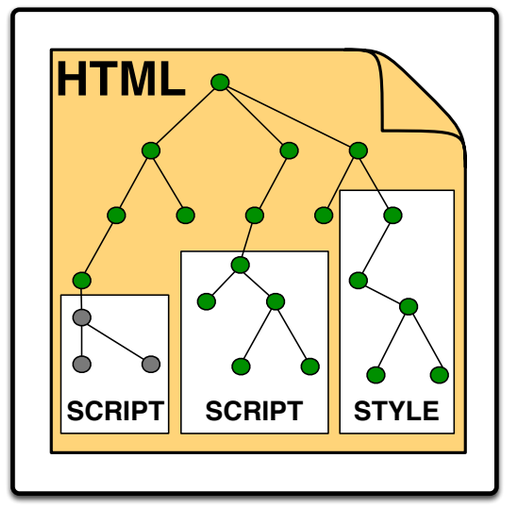
Inputs

Web App

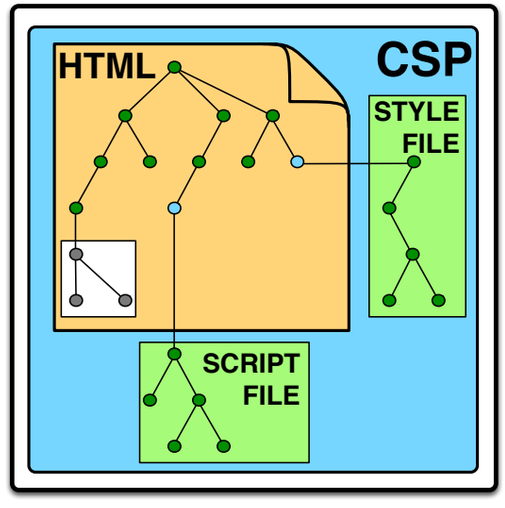
Dynamic Tainting



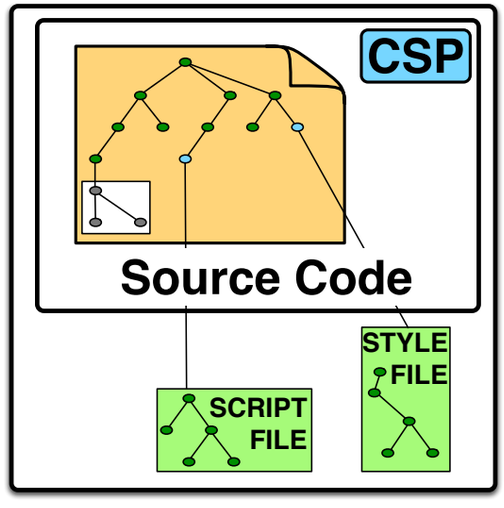
Web Page Analysis



CSP Analysis



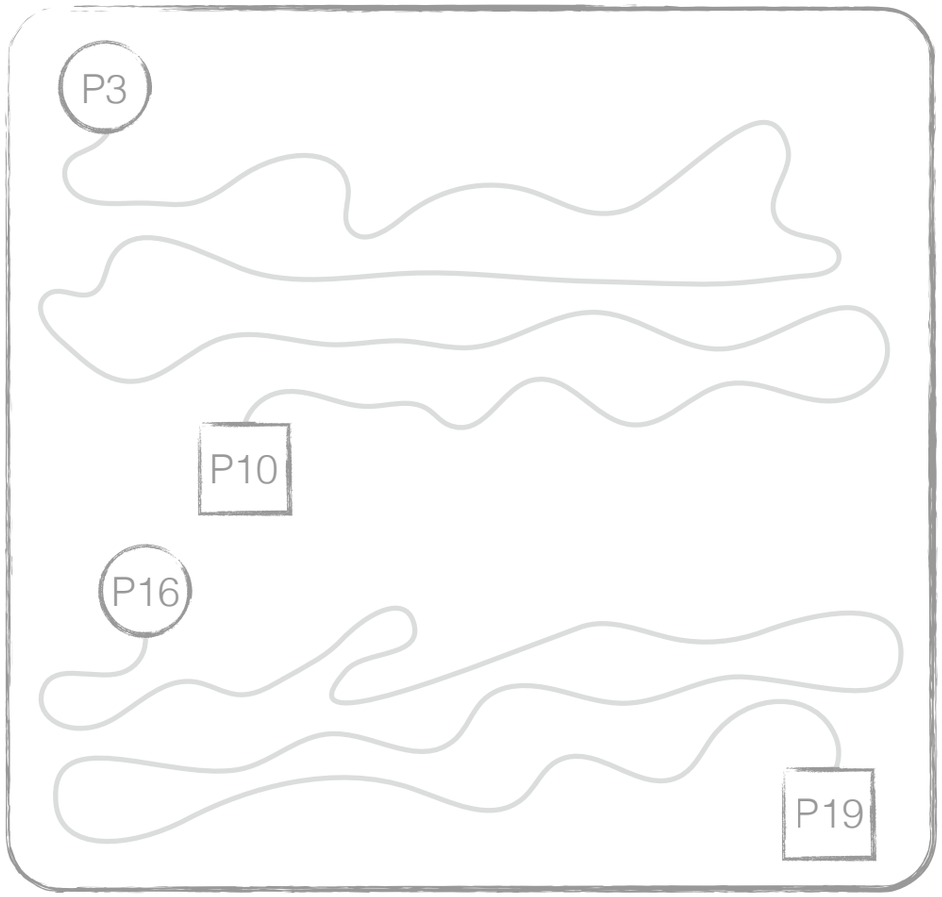
Source Code Transformation



Transformed Web App

(1) Dynamic Tainting

Positive Dynamic Tainting

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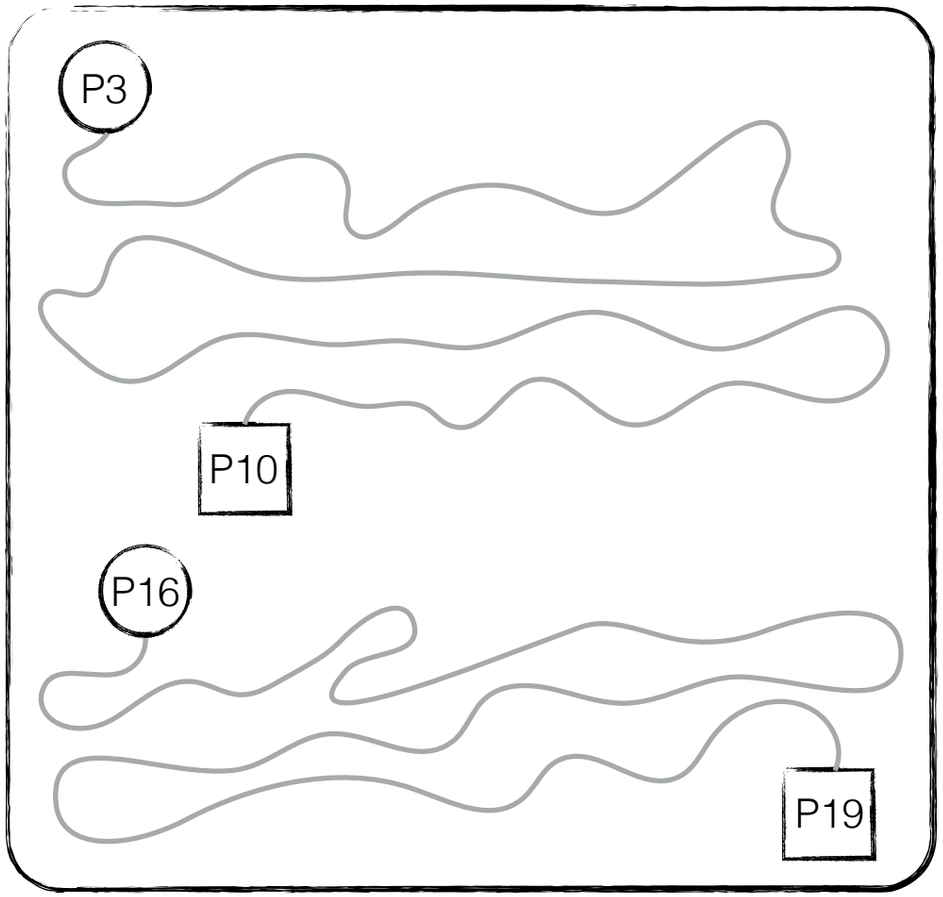
...
 3 $out="<script>
 4  function grades(){
 5    document.student.page2.value=3;
 6    document.student.submit();
 7  }
 8  </script>"
...
10 print($out);
...
16 while($assignment =
17  mysql_fetch_row($query)){
18   ...
19   print("<td style='text-align:left;'>"
20    .$assignment[5].
21    "</td>");
```

(1) Dynamic Tainting

Positive Dynamic Tainting

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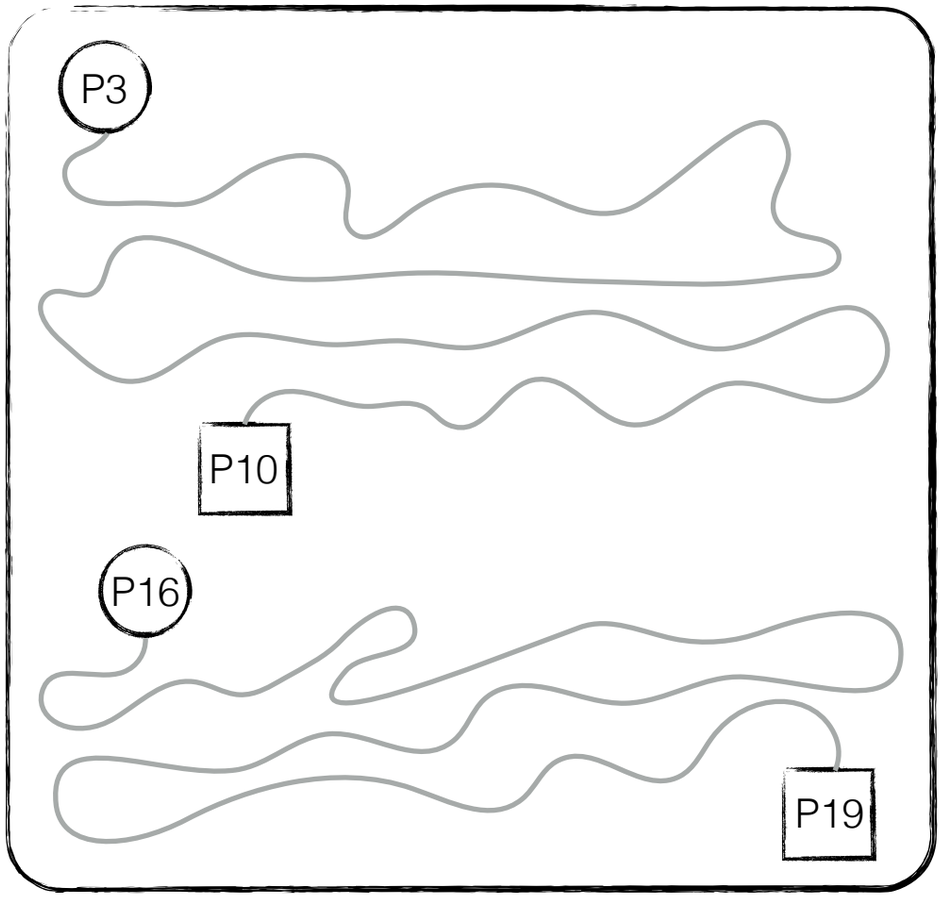


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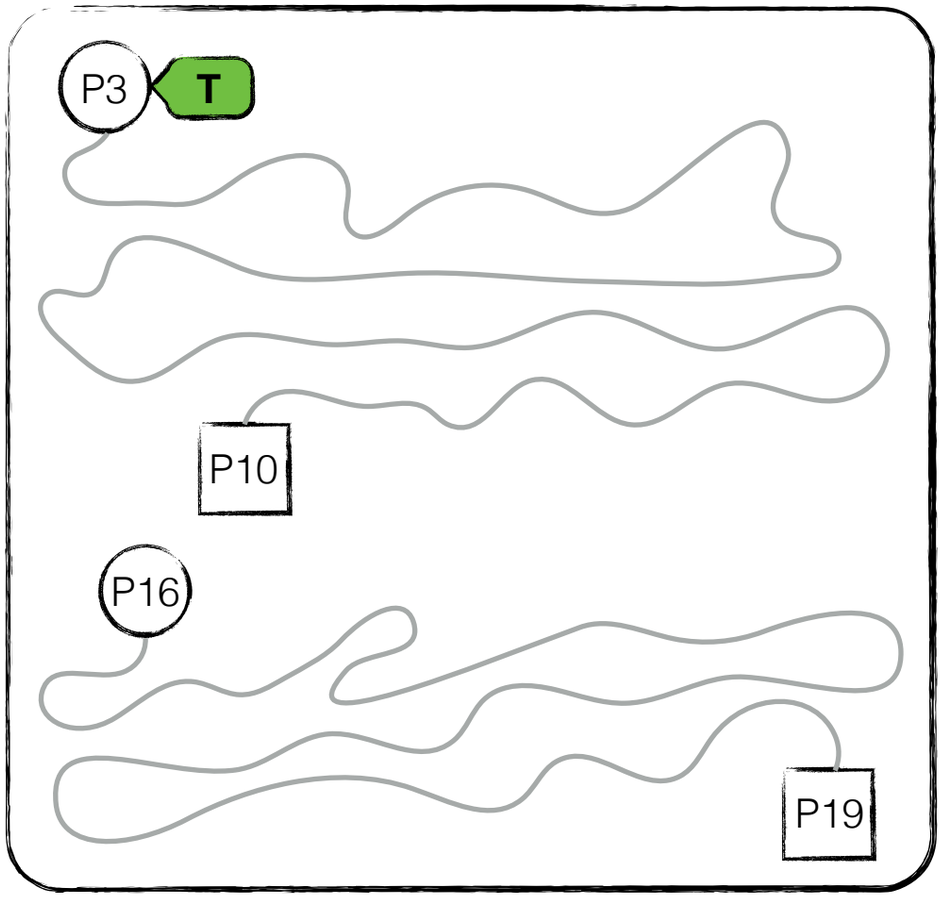


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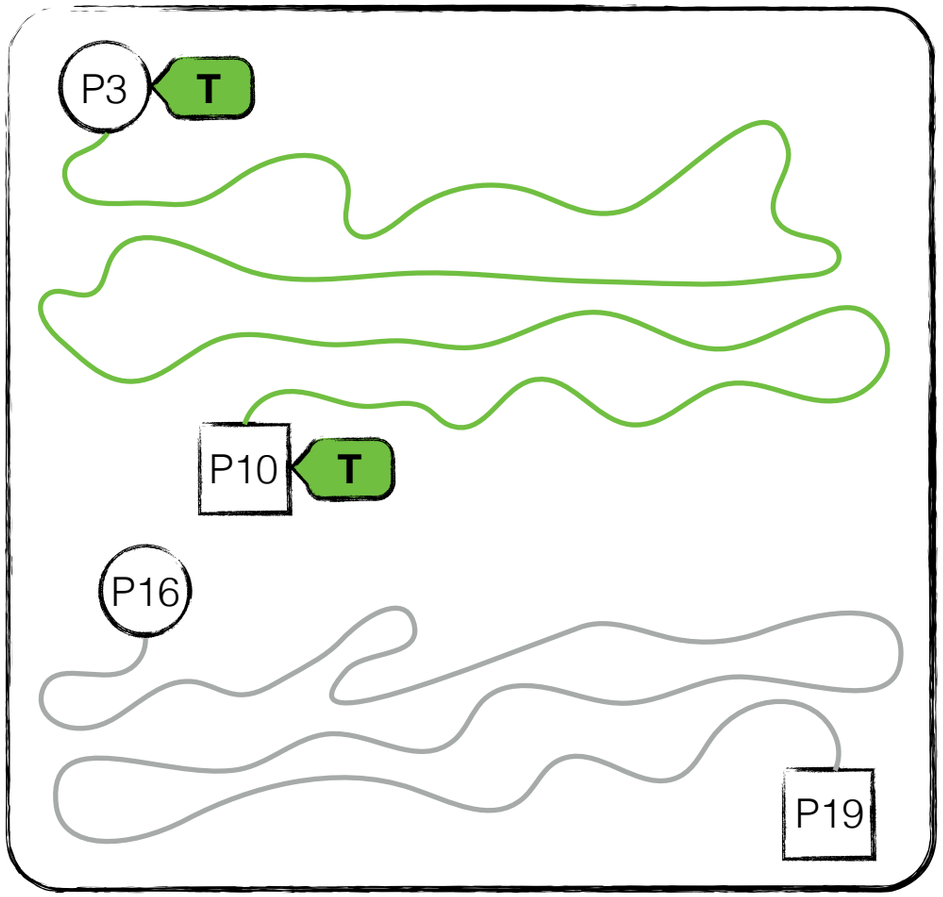


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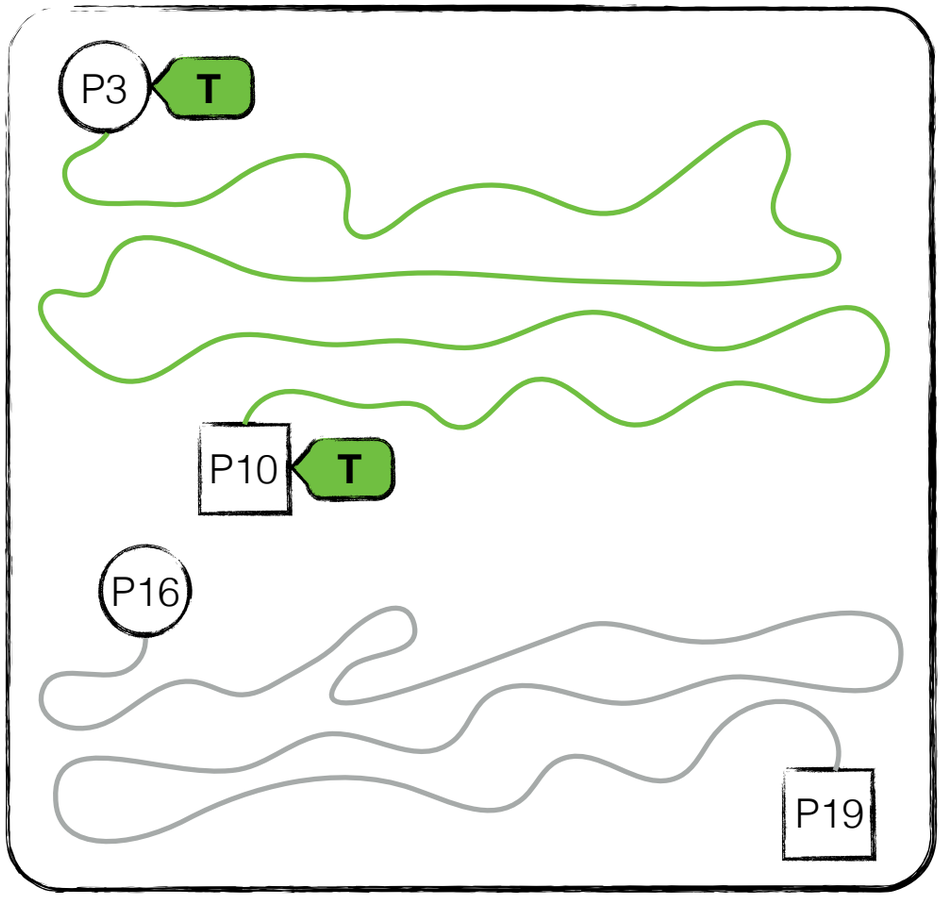


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```

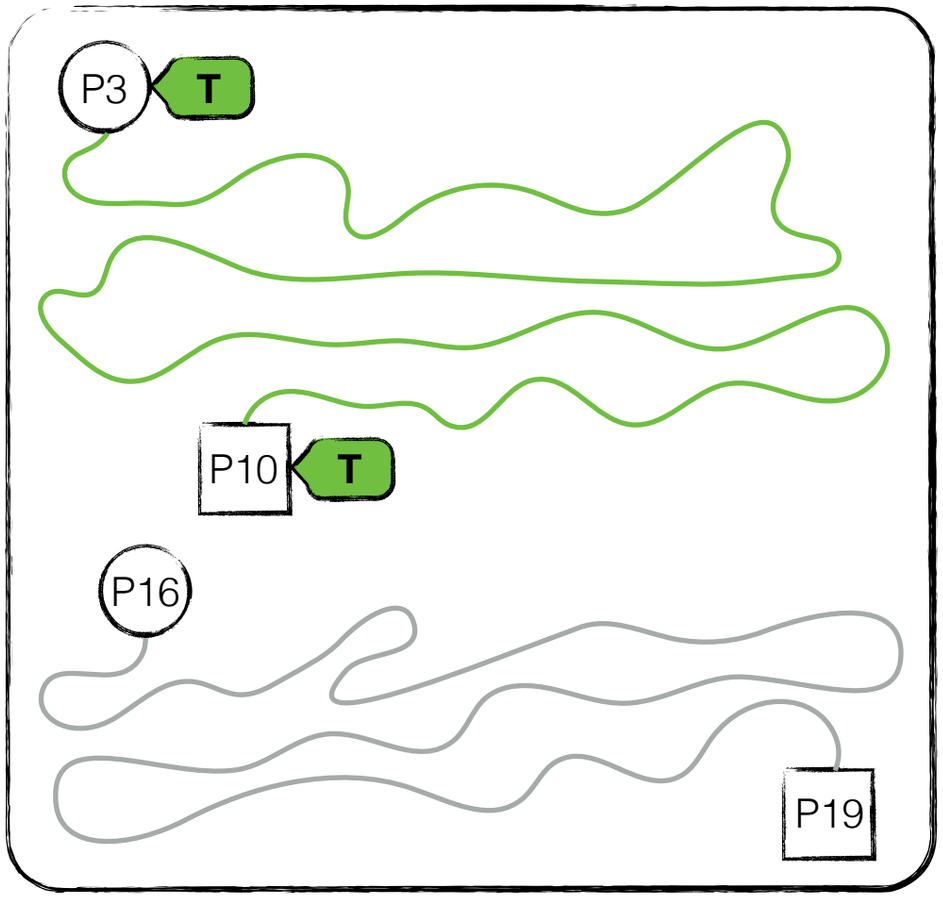
HTML buffer

Taint buffer

Source buffer

(1) Dynamic Tainting

Positive Dynamic Tainting

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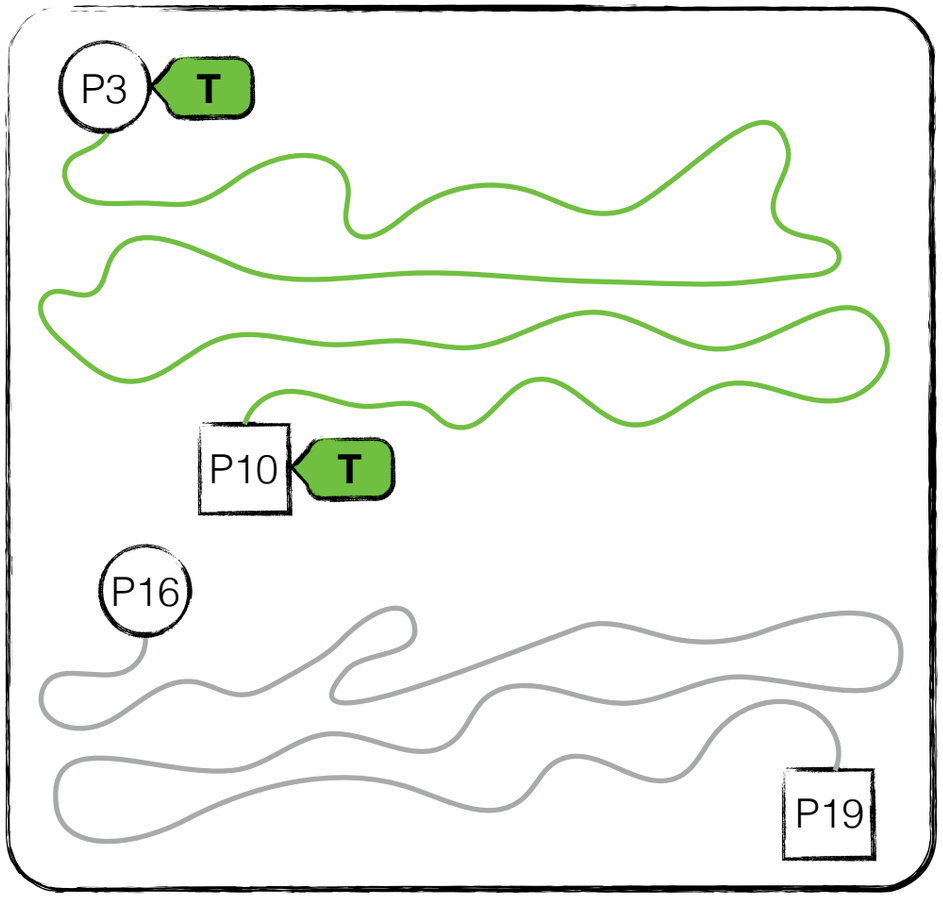
HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>															
Taint buffer																																
Source buffer																																

(1) Dynamic Tainting

Positive Dynamic Tainting

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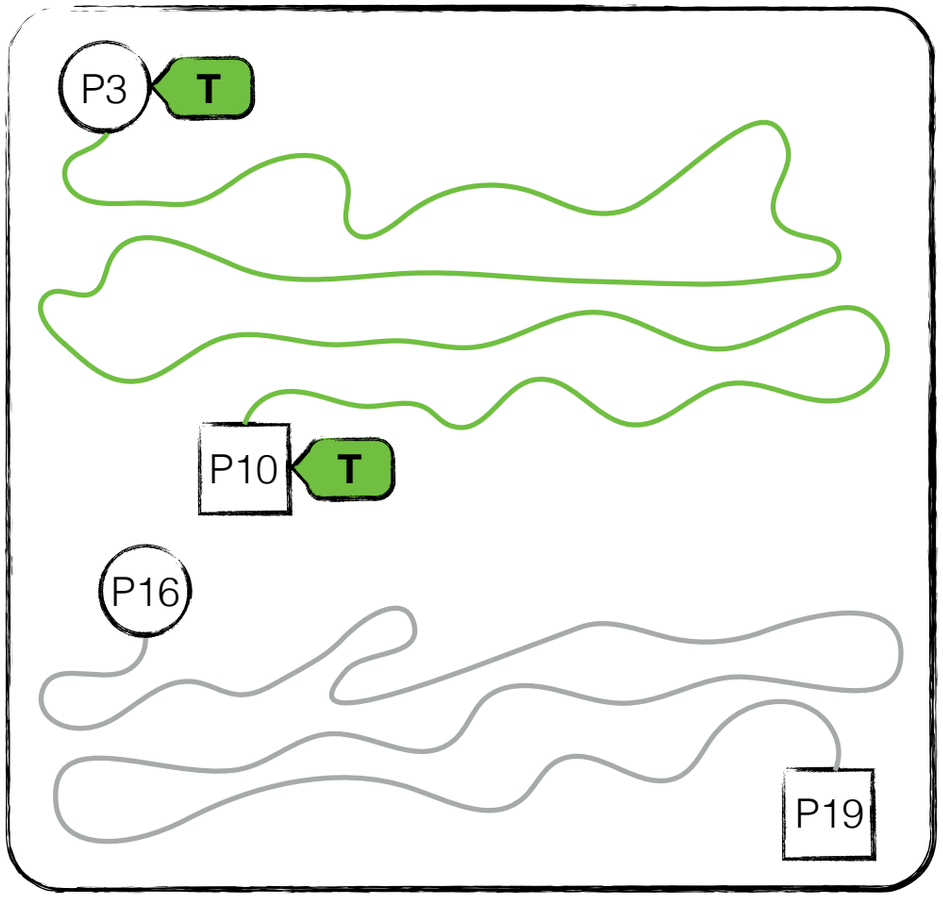
HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Source buffer																	

(1) Dynamic Tainting

Positive Dynamic Tainting

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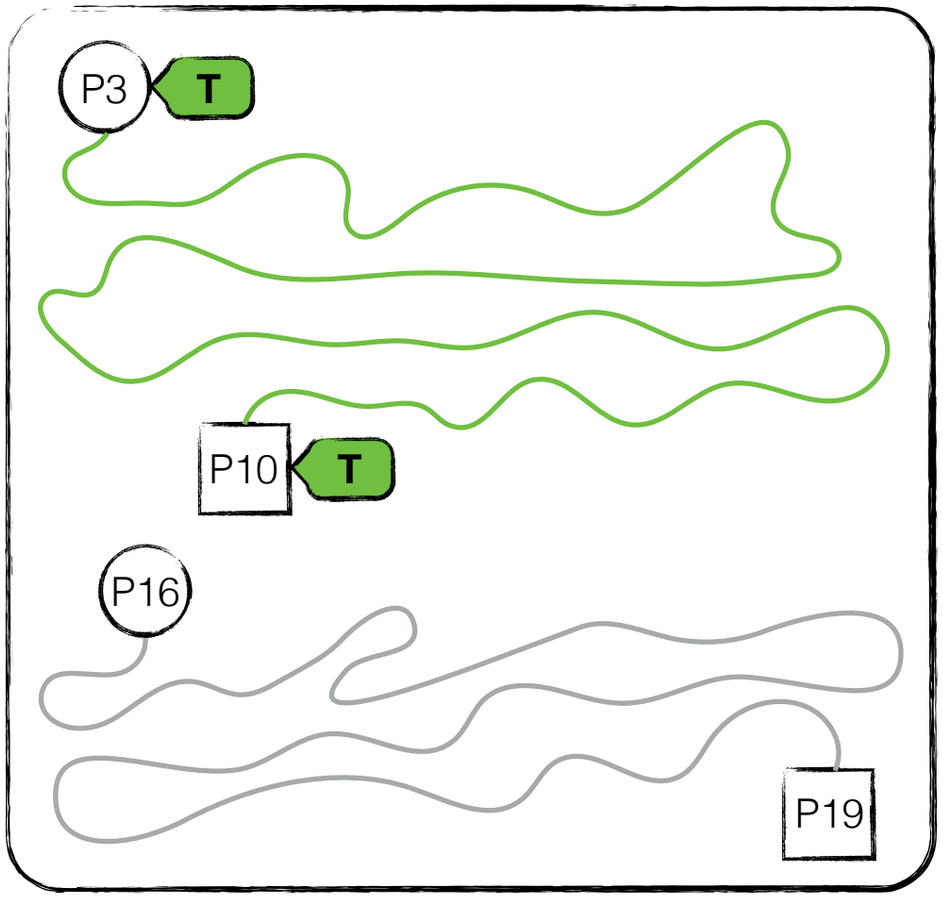
HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

(1) Dynamic Tainting

Positive Dynamic Tainting

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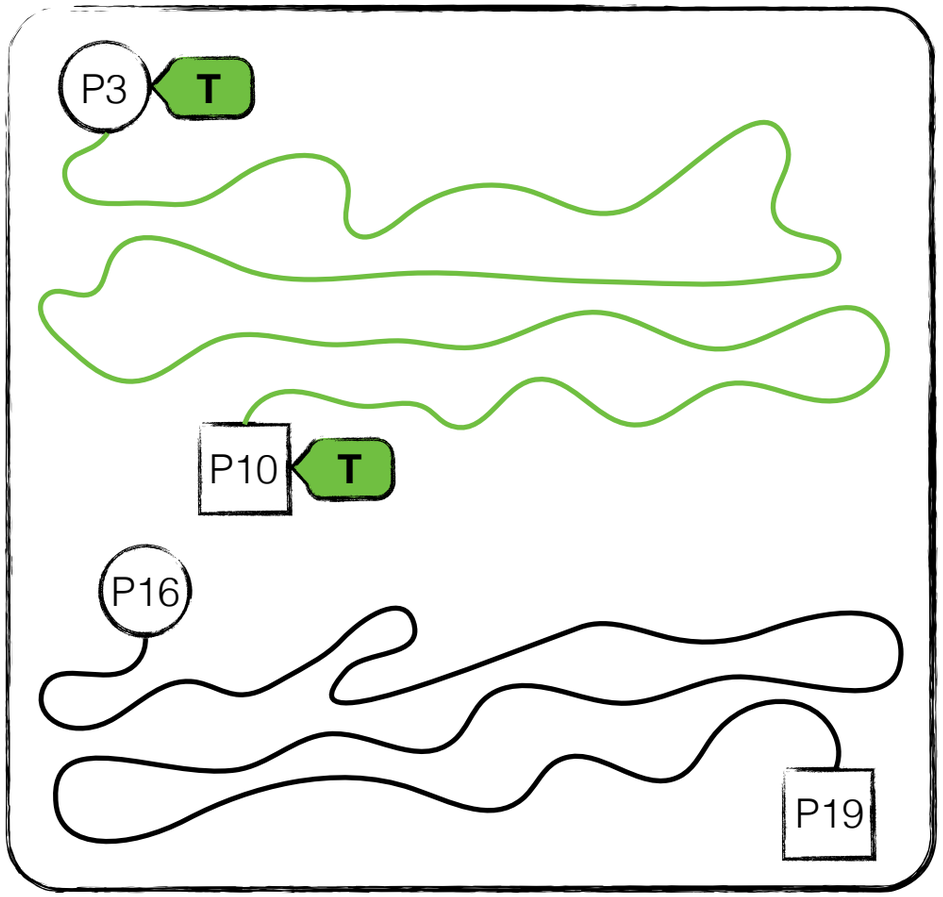
```

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

(1) Dynamic Tainting

Positive Dynamic Tainting

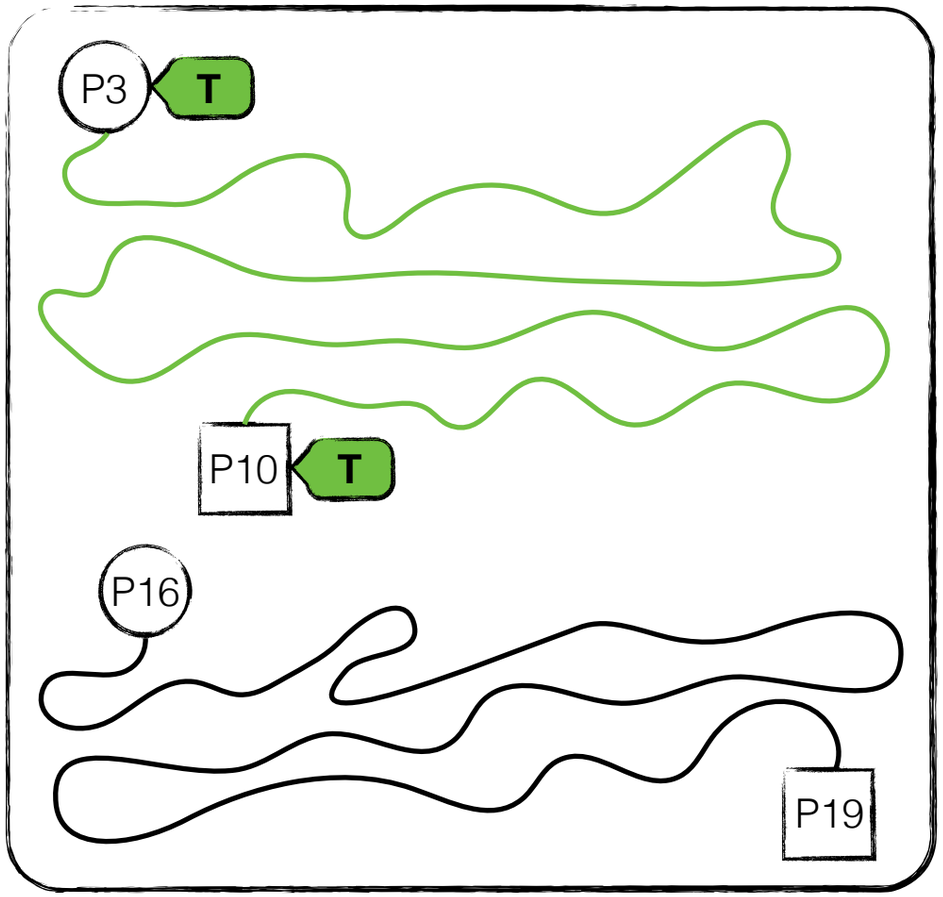



```
…
 3 $out="<script>
 4  function grades(){
 5    document.student.page2.value=3;
 6    document.student.submit();
 7  }
 8  </script>"
…
10 print($out);
…
16 while($assignment =
17  mysql_fetch_row($query)){
18   ...
19   print("<td style='text-align:left;'>"
20    .$assignment[5].
21    "</td>");
```

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

(1) Dynamic Tainting

Positive Dynamic Tainting

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 3 $out="<script>
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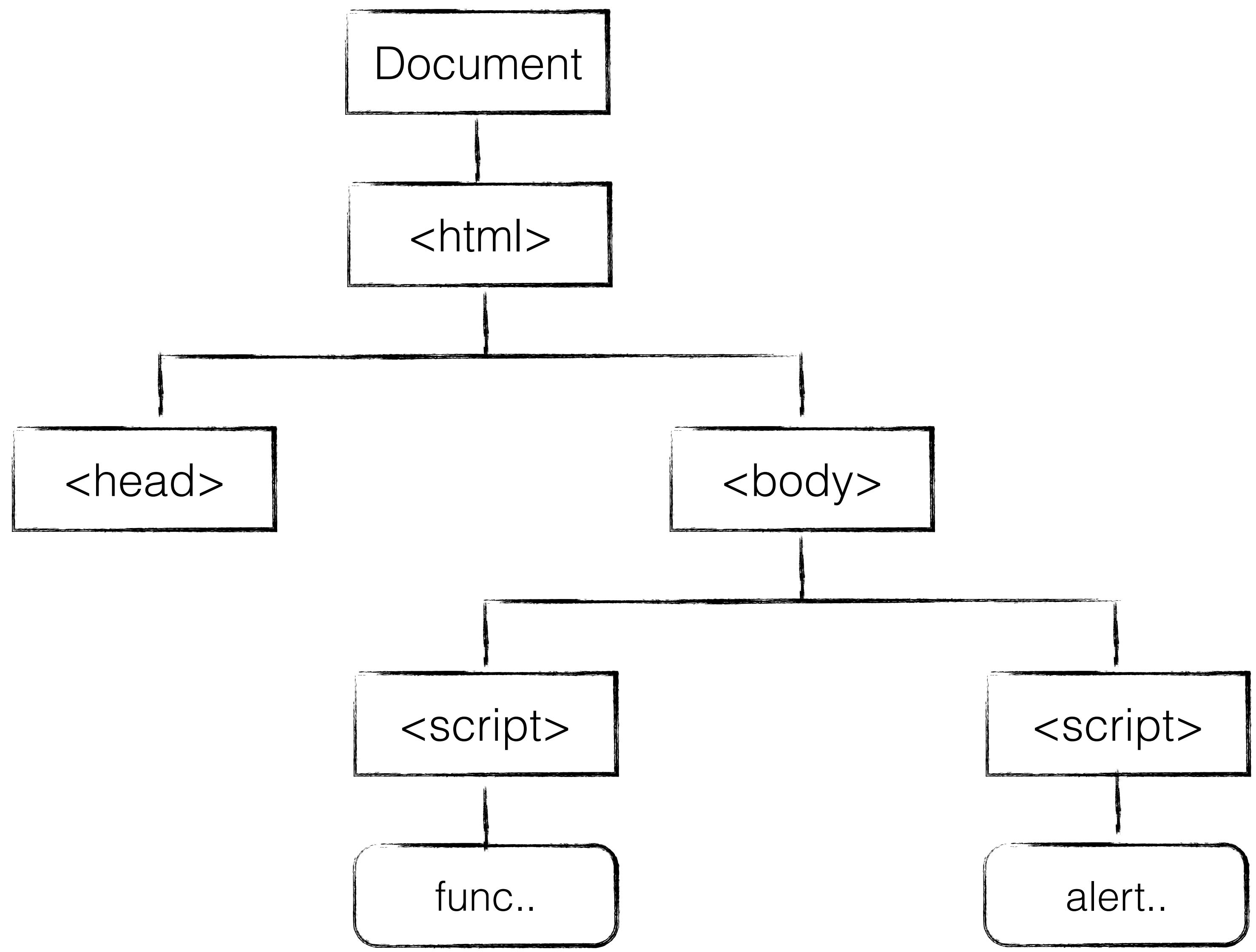
HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>	.	.	<	s	c	r	i	p	t	>	a	l	e	r	t	.	.
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	.	.														.	.
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	.	.														.	.

(2) Web Page Analysis

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>	.	.	<	s	c	r	i	p	t	>	a	l	e	r	t	.	.
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	.	.														.	.
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	.	.														.	.

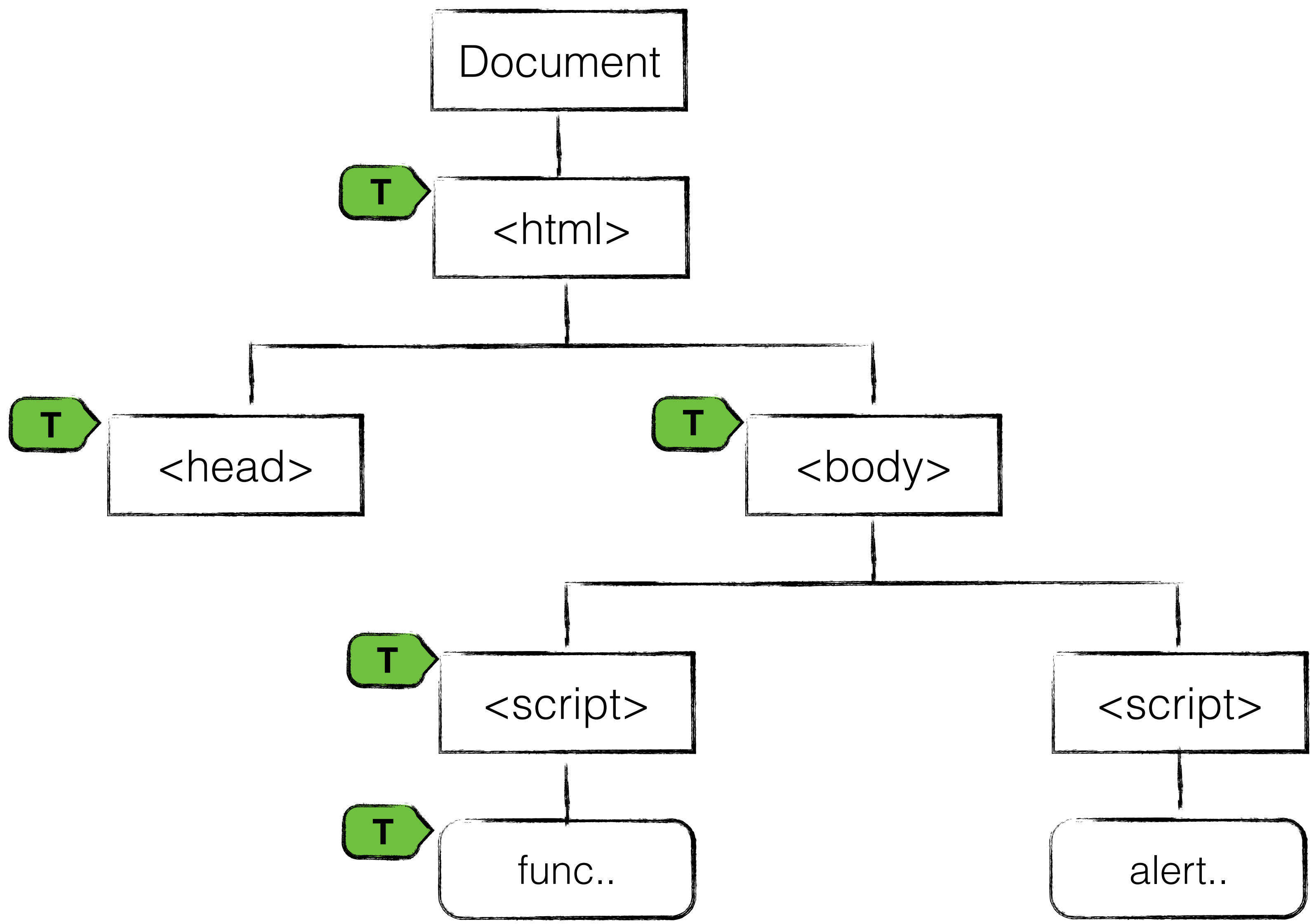
(2) Web Page Analysis

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>	.	.	<	s	c	r	i	p	t	>	a	l	e	r	t	.	.
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	.	.														.	.
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	.	.														.	.



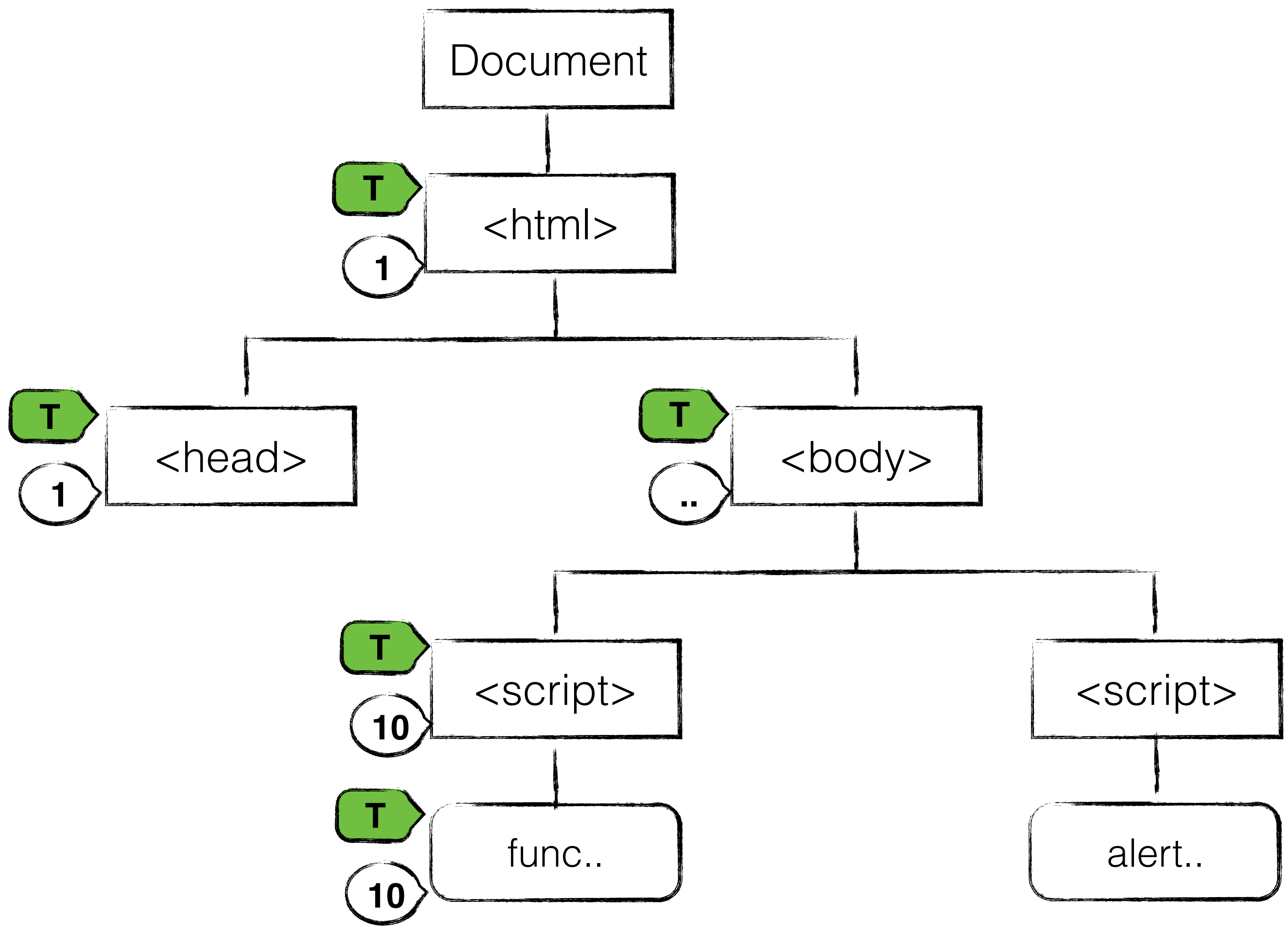
(2) Web Page Analysis

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>	.	.	<	s	c	r	i	p	t	>	a	l	e	r	t	.	.
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	.	.														.	.
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	.	.														.	.



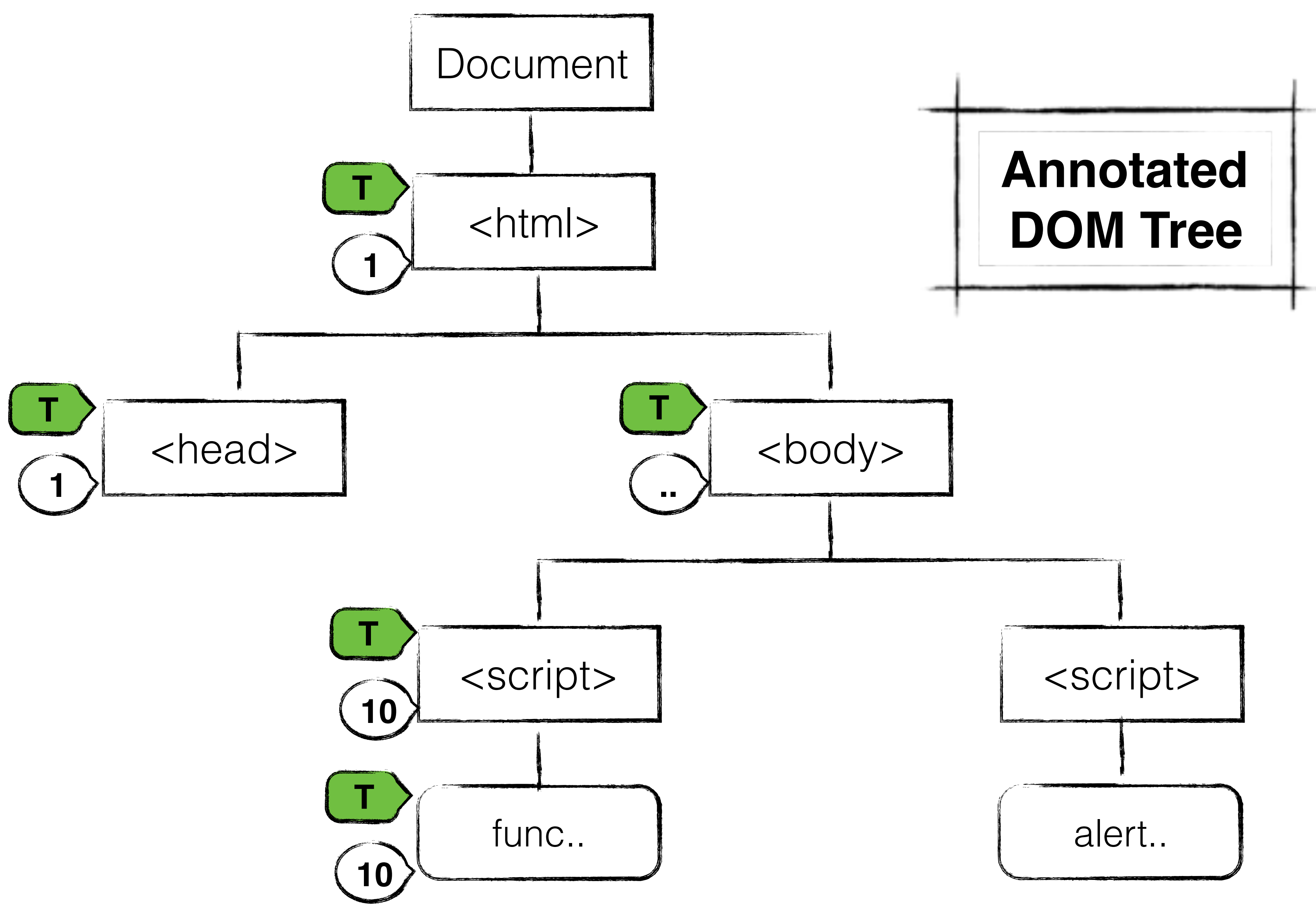
(2) Web Page Analysis

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>	.	.	<	s	c	r	i	p	t	>	a	l	e	r	t	.	.
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	.	.																.	.
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	.	.																.	.

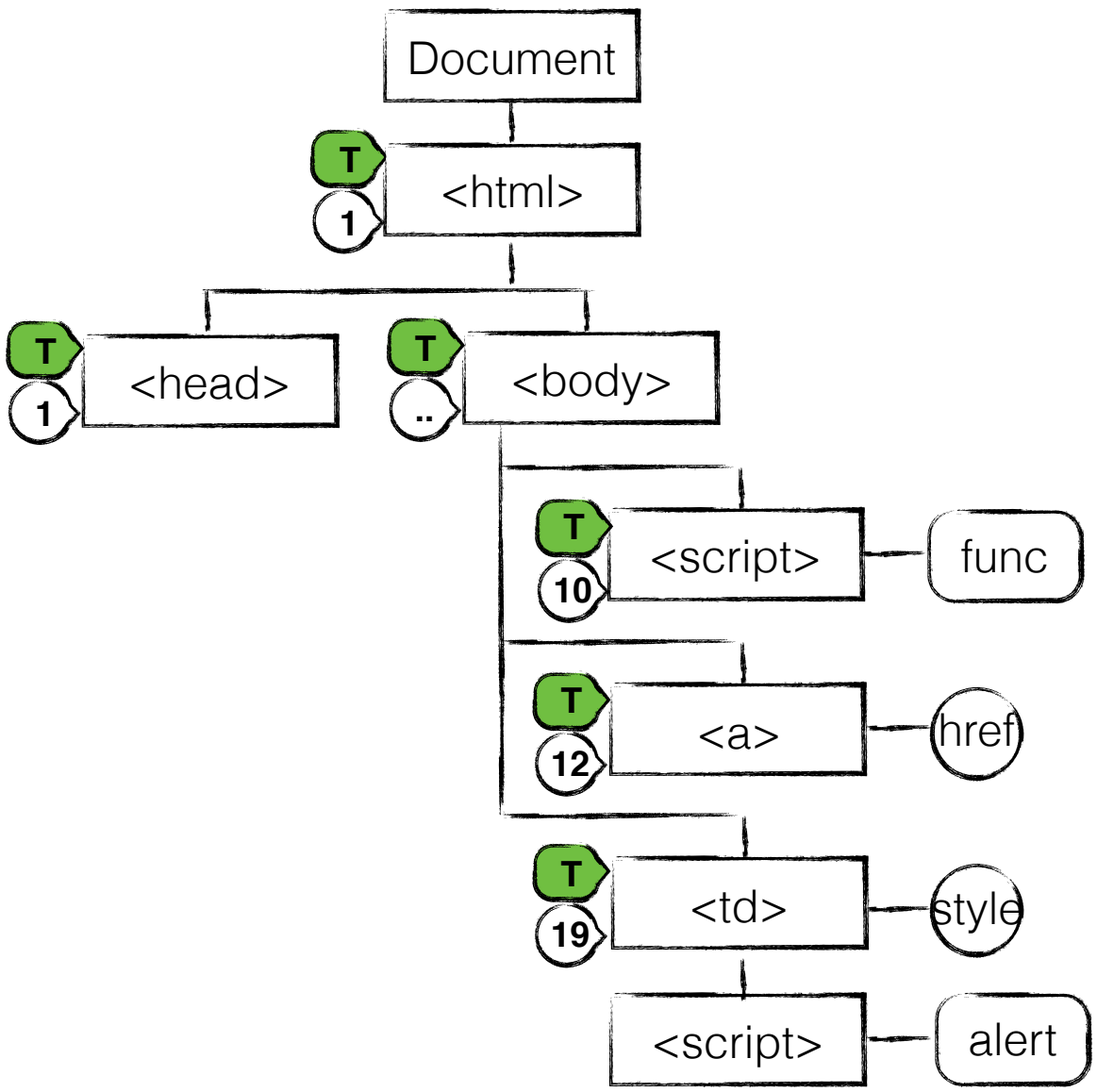


(2) Web Page Analysis

HTML buffer	.	.	<	s	c	r	i	p	t	>	f	u	n	c	.	.	>	.	.	<	s	c	r	i	p	t	>	a	l	e	r	t	.	.
Taint buffer	.	.	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	.	.														.	.
Source buffer	.	.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	.	.														.	.

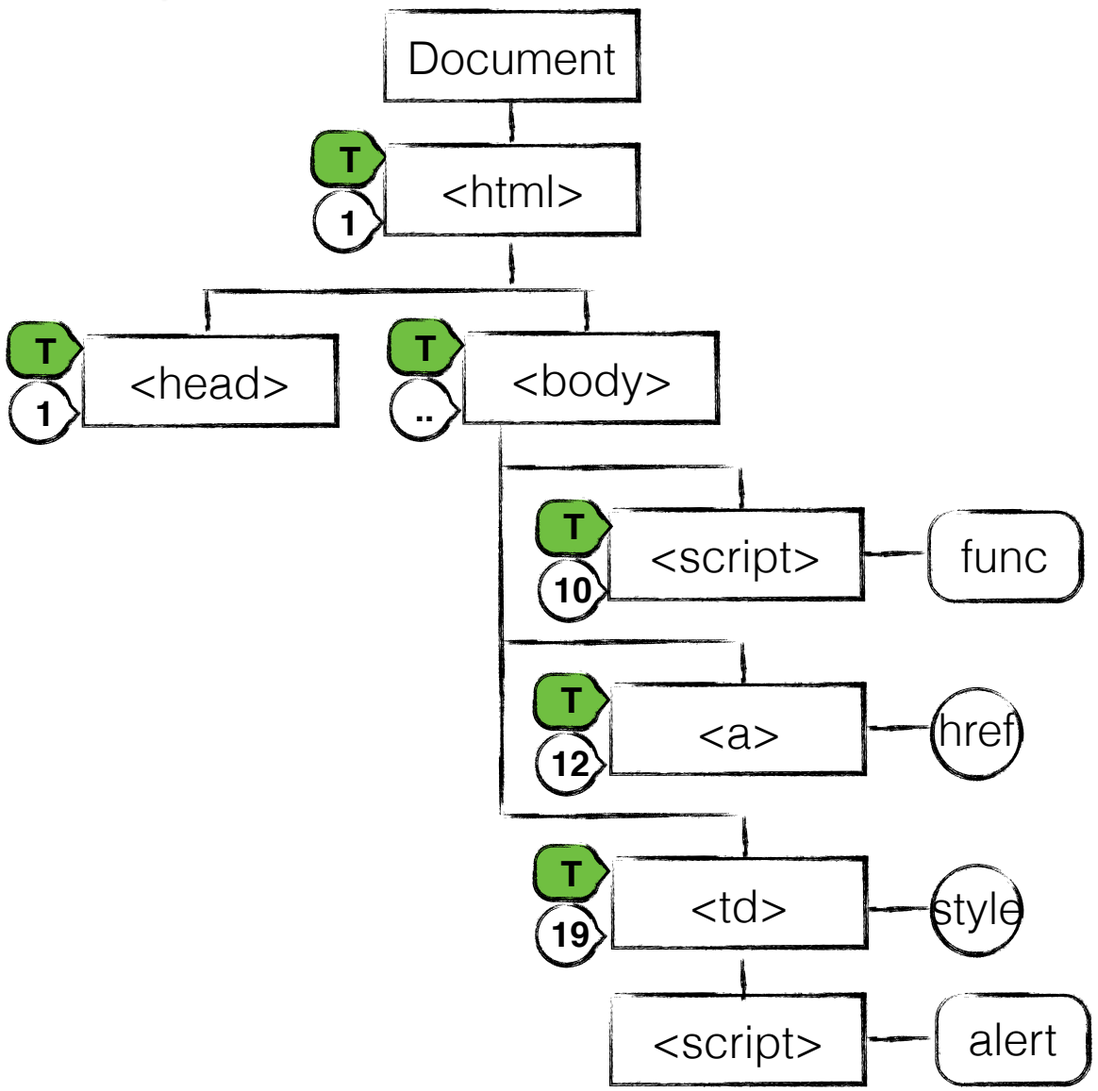


(3) CSP Analysis



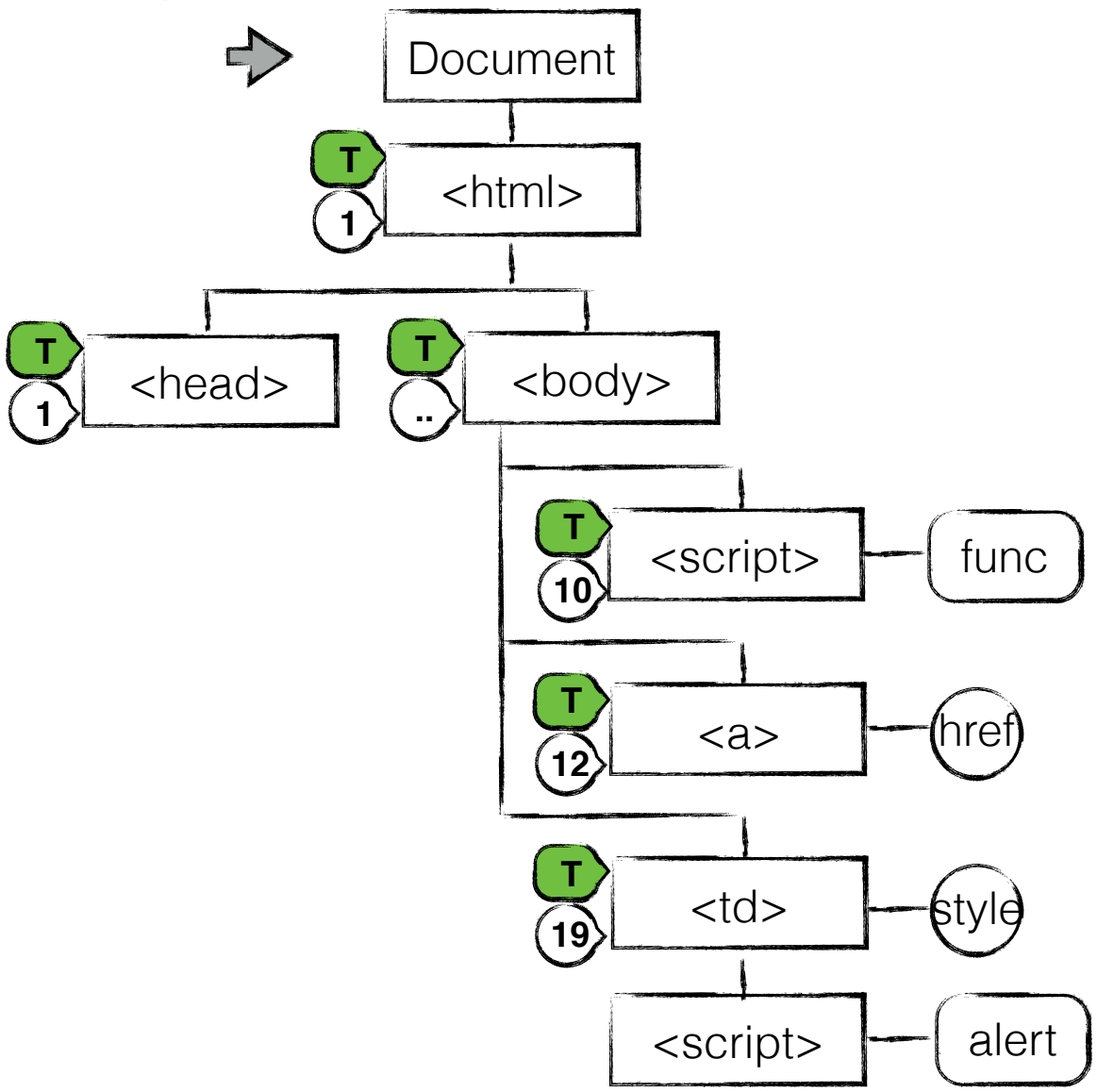
(3) CSP Analysis

Content-Security-Policy: default-src ‘none’



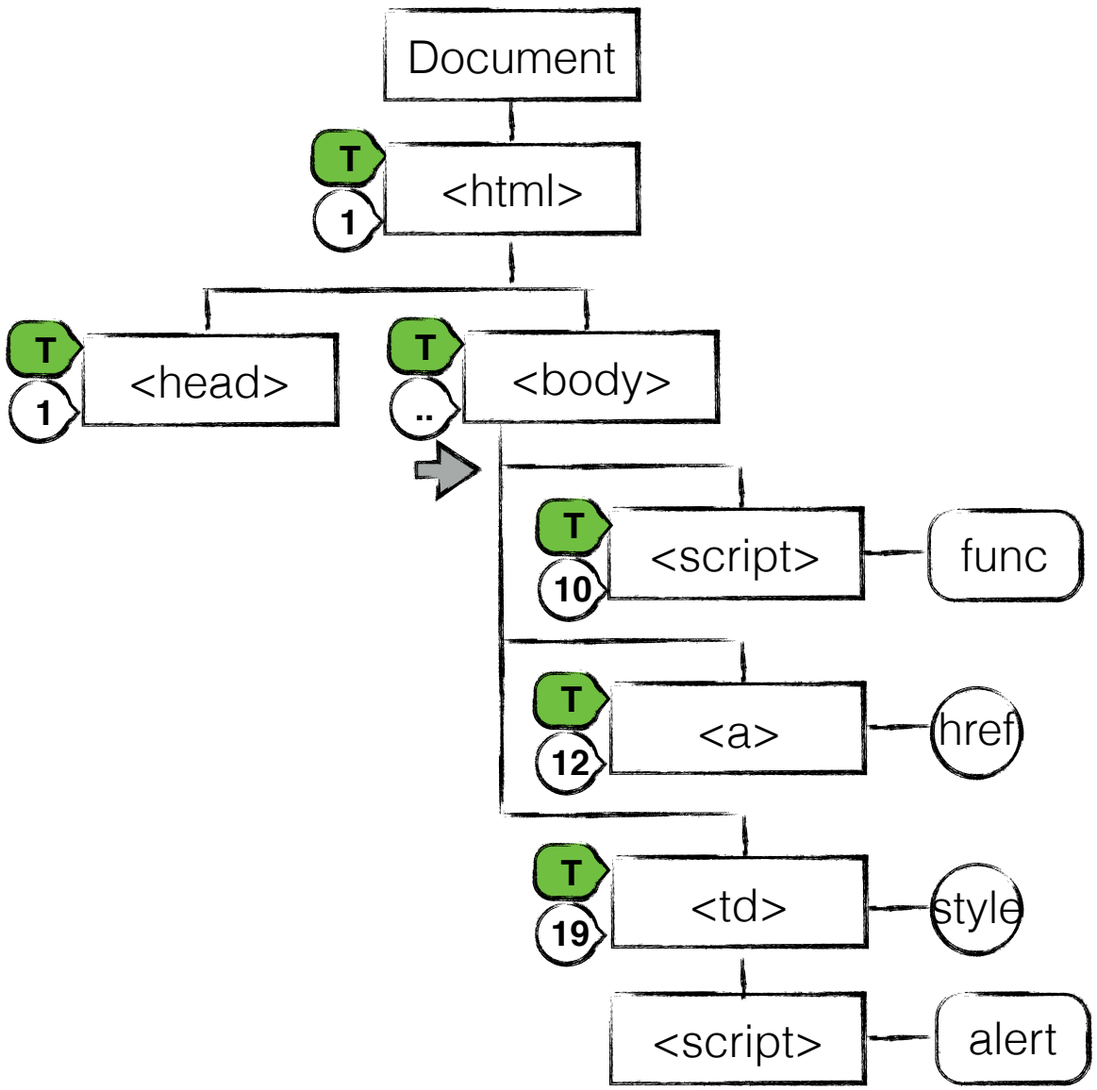
(3) CSP Analysis

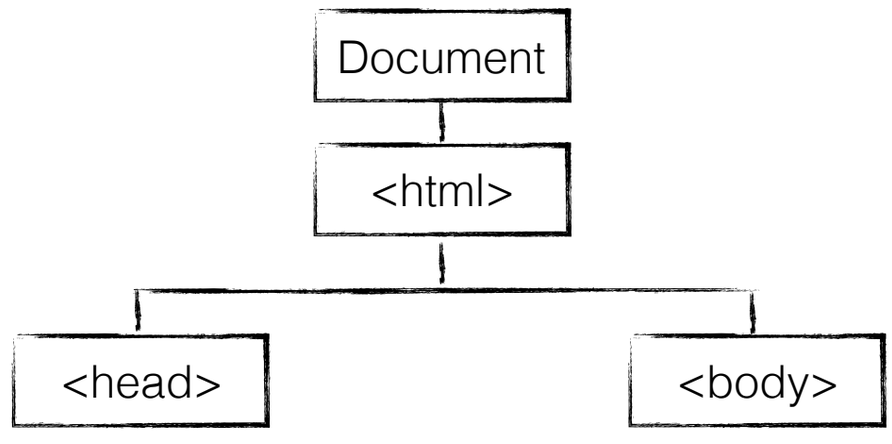
Content-Security-Policy: default-src ‘none’



(3) CSP Analysis

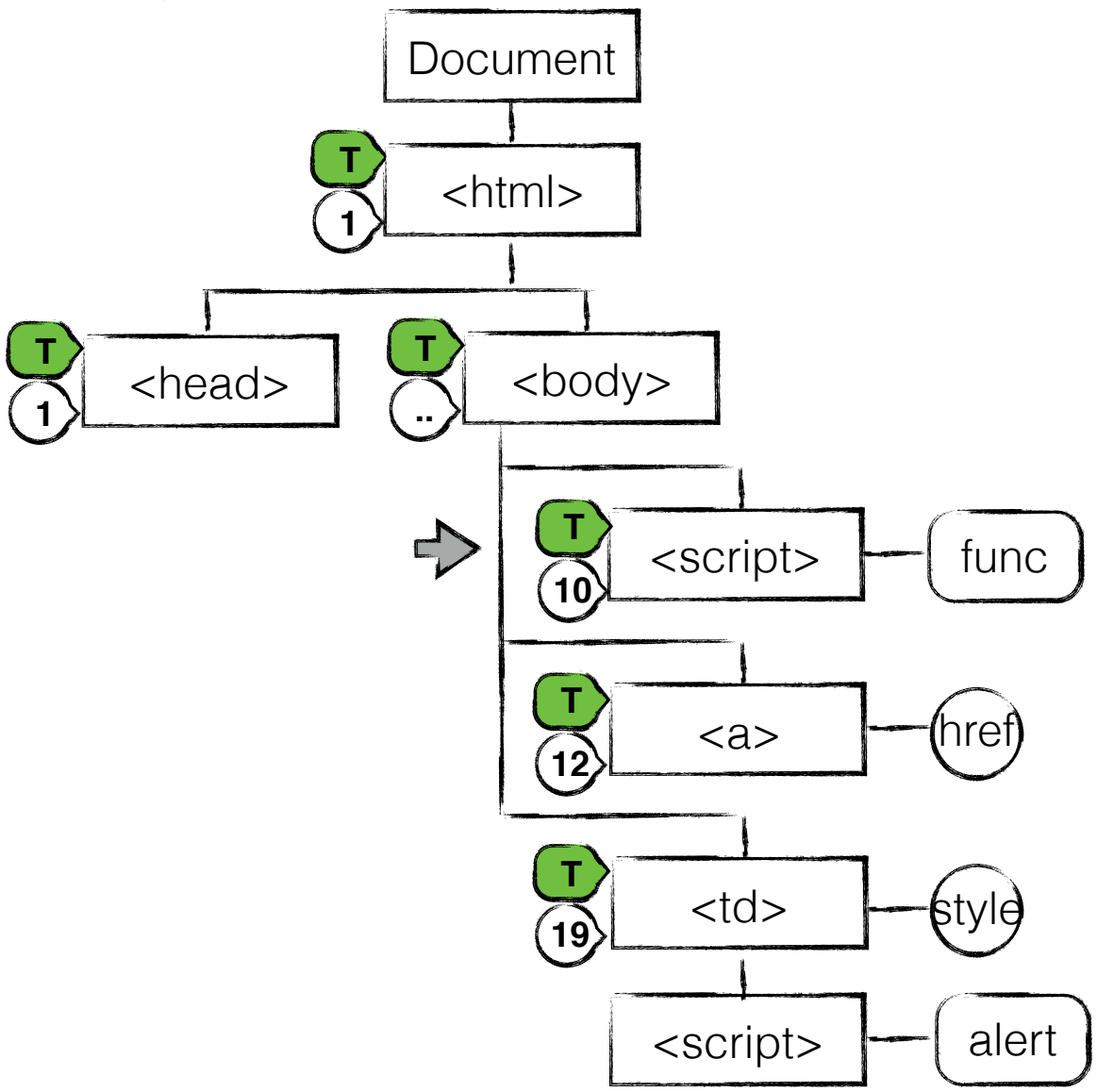
Content-Security-Policy: default-src ‘none’

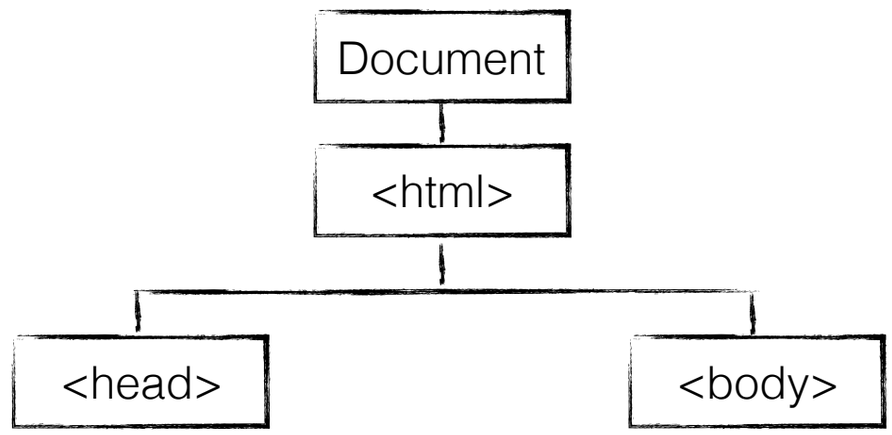




(3) CSP Analysis

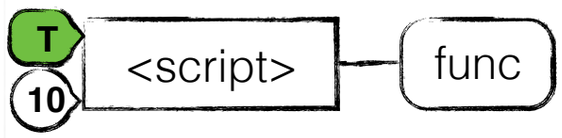
Content-Security-Policy: default-src ‘none’



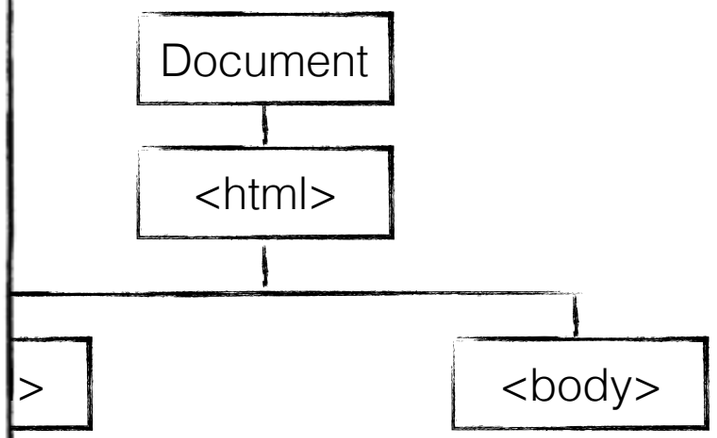


(3) CSP Analysis

Content-Security-Policy: default-src ‘none’

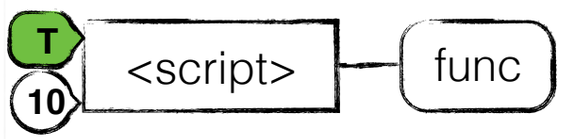



```
<script>
 function grades(){
  document.student.page2.value=3;
  document.student.submit();
 }
</script>
```

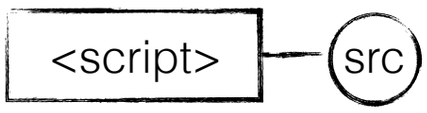


(3) CSP Analysis

Content-Security-Policy: default-src ‘none’




```
<script>
 function grades(){
  document.student.page2.value=3;
  document.student.submit();
 }
</script>
```

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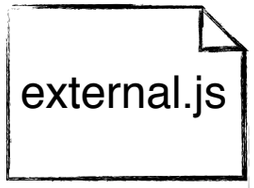
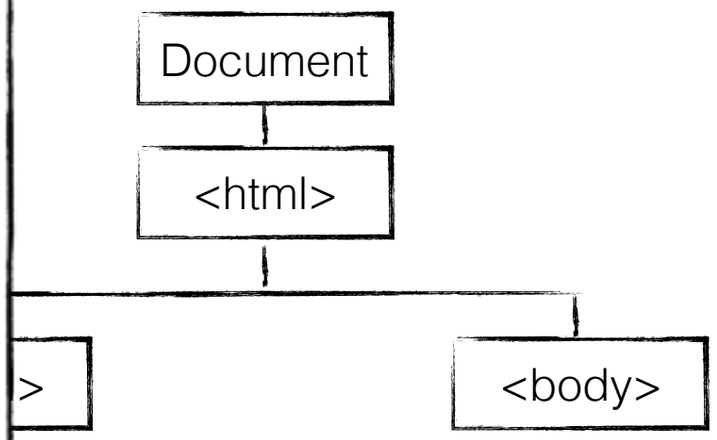
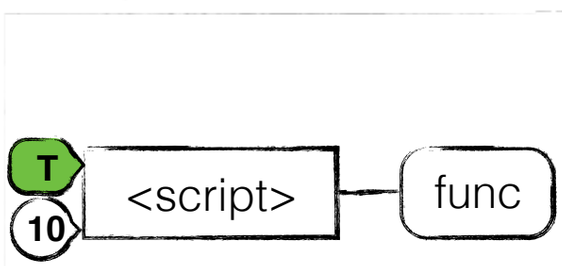


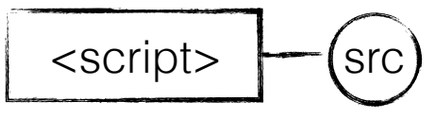


(3) CSP Analysis

Content-Security-Policy: default-src ‘none’, **script-src ‘self'**




```
<script>
 function grades(){
  document.student.page2.value=3;
  document.student.submit();
 }
</script>
```




```
<script src='external.js'>
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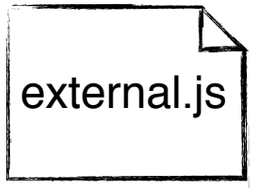
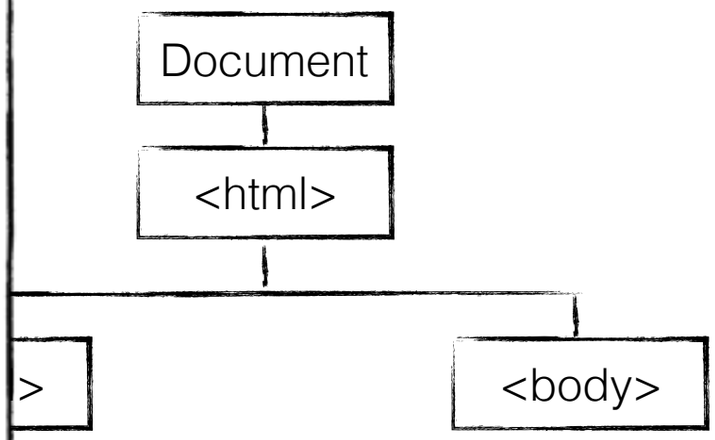
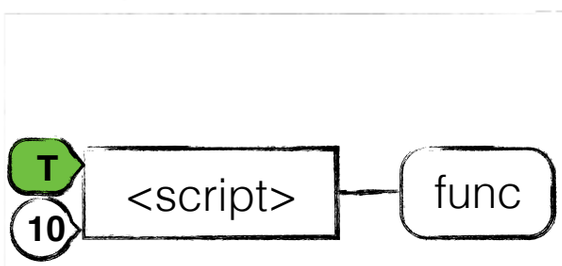




(3) CSP Analysis

Content-Security-Policy: default-src ‘none’, script-src ‘self'




```
<script>
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  document.student.page2.value=3;
  document.student.submit();
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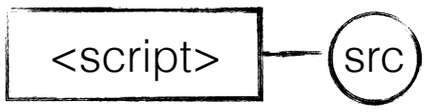
</script>
```

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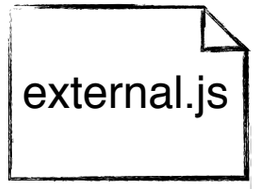
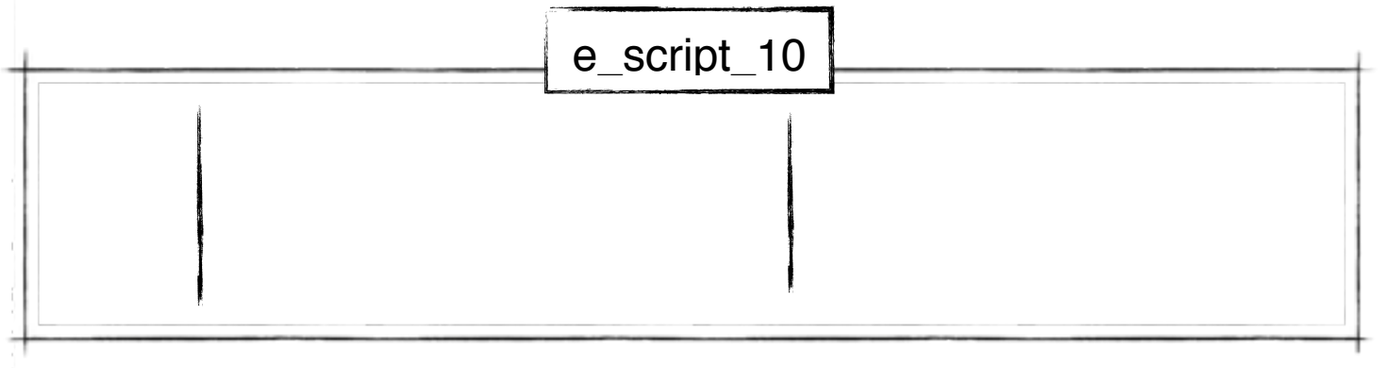
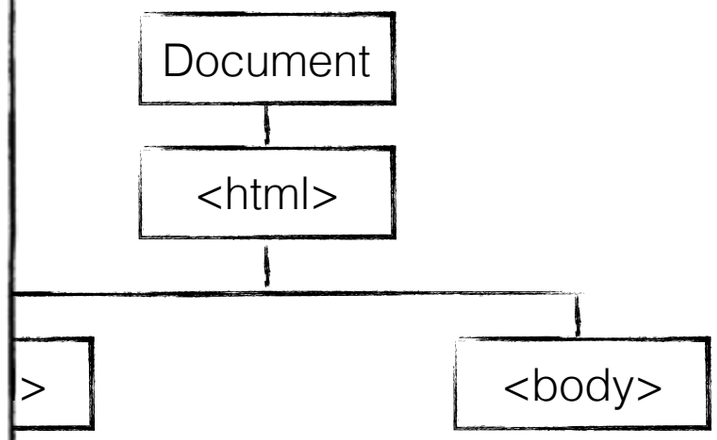
</script>
```

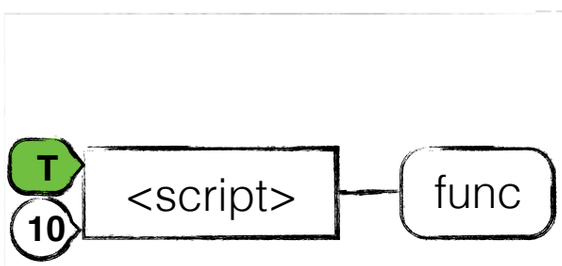






(3) CSP Analysis

Content-Security-Policy: default-src ‘none’, script-src ‘self'

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<script>
 function grades(){
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  document.student.submit();
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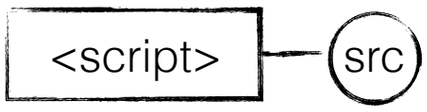


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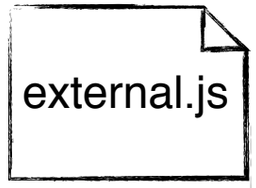
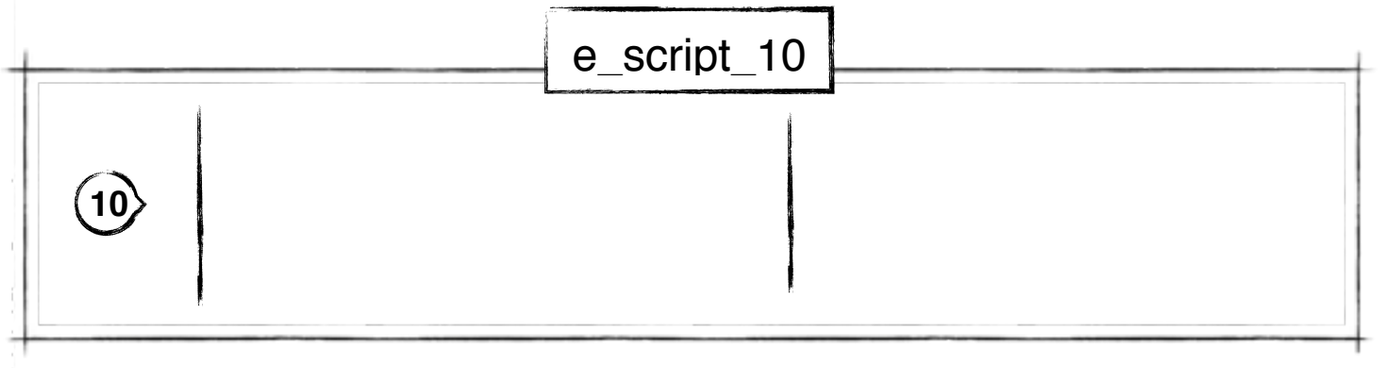
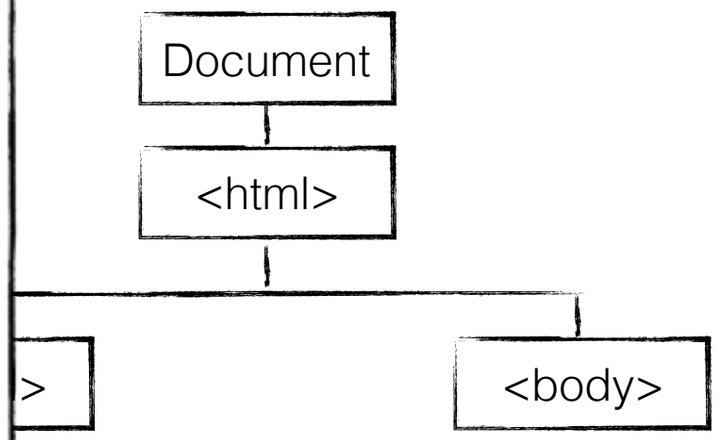
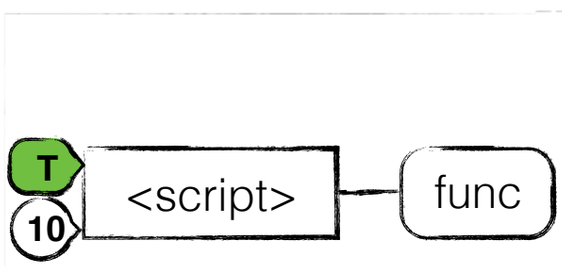




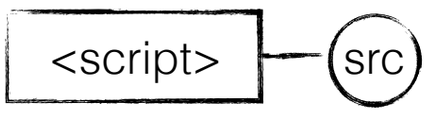


(3) CSP Analysis

Content-Security-Policy: default-src ‘none’, script-src ‘self'




```
<script>
 function grades(){
  document.student.page2.value=3;
  document.student.submit();
 }
</script>
```



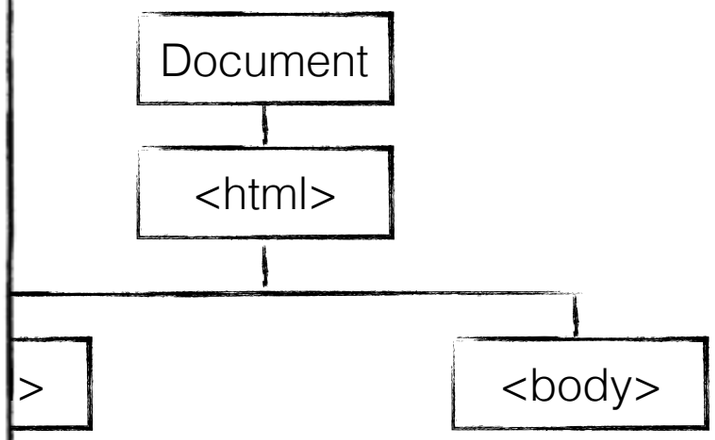

```
<script src='external.js'>
</script>
```

external.js

e_script_10

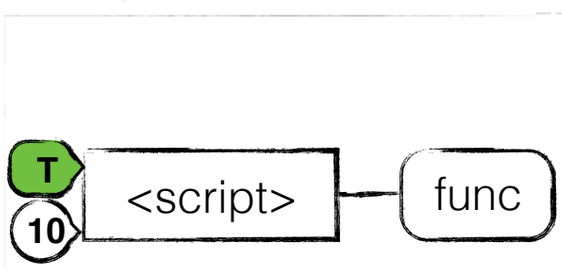
10

```
<script>
 function grades(){…}
</script>
```

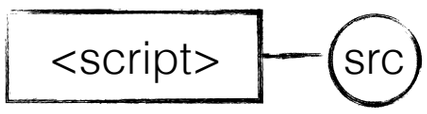


(3) CSP Analysis

Content-Security-Policy: default-src ‘none’, script-src ‘self'




```
<script>
 function grades(){
  document.student.page2.value=3;
  document.student.submit();
 }
</script>
```

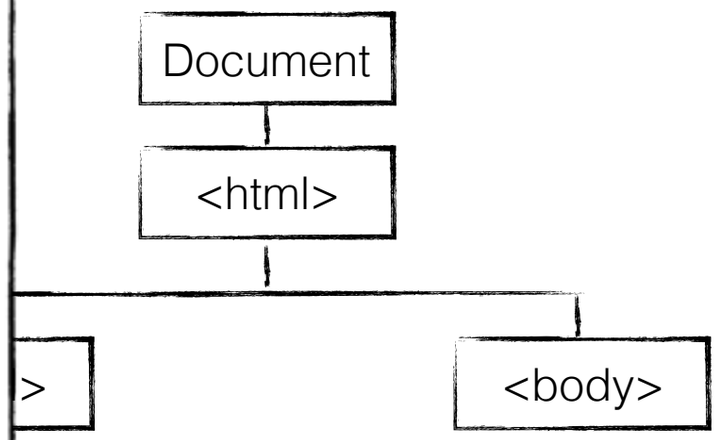



```
<script src='external.js'>
</script>
```

external.js

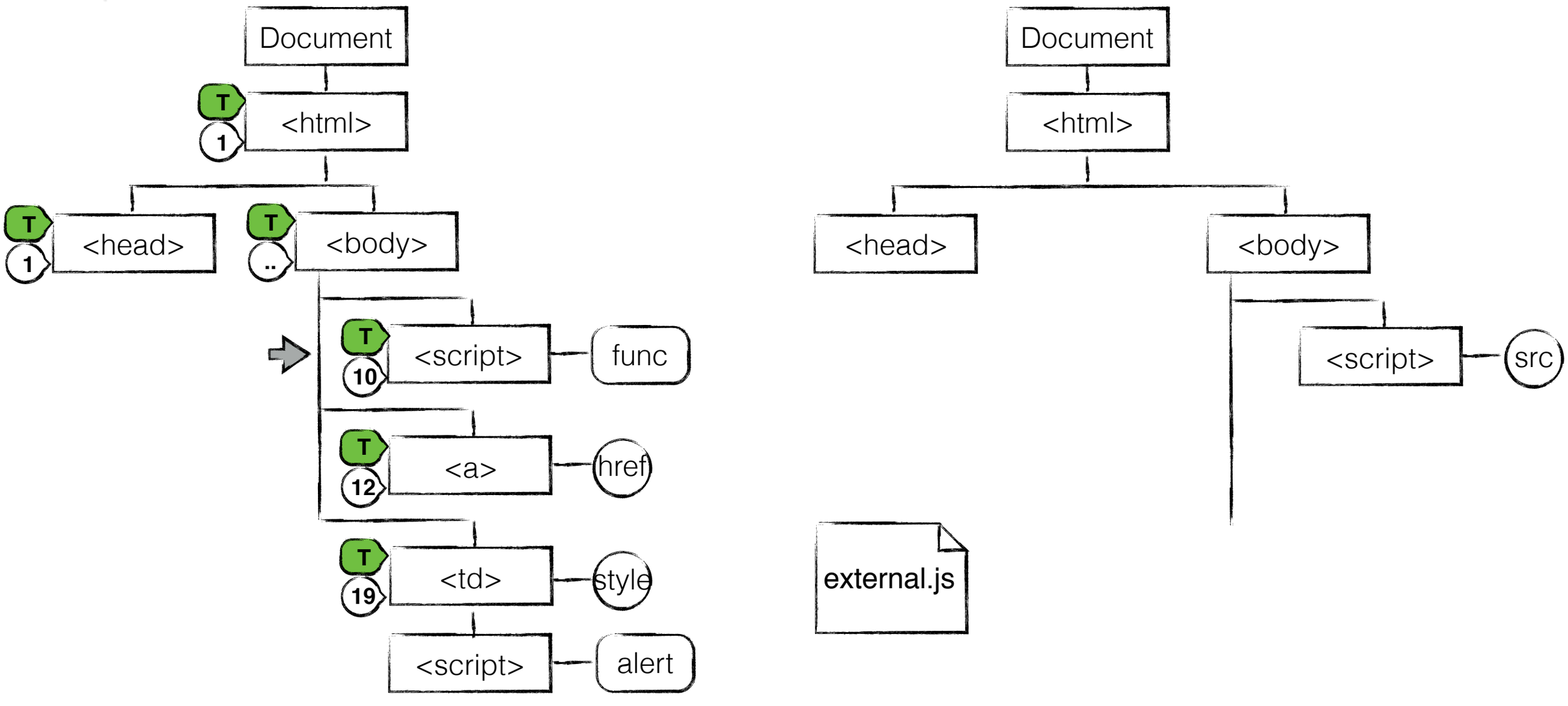
e_script_10

10	`<script>`
	`function grades(){…}`
	`</script>`
		`<script src='external.js'>`
		`</script>`



(3) CSP Analysis

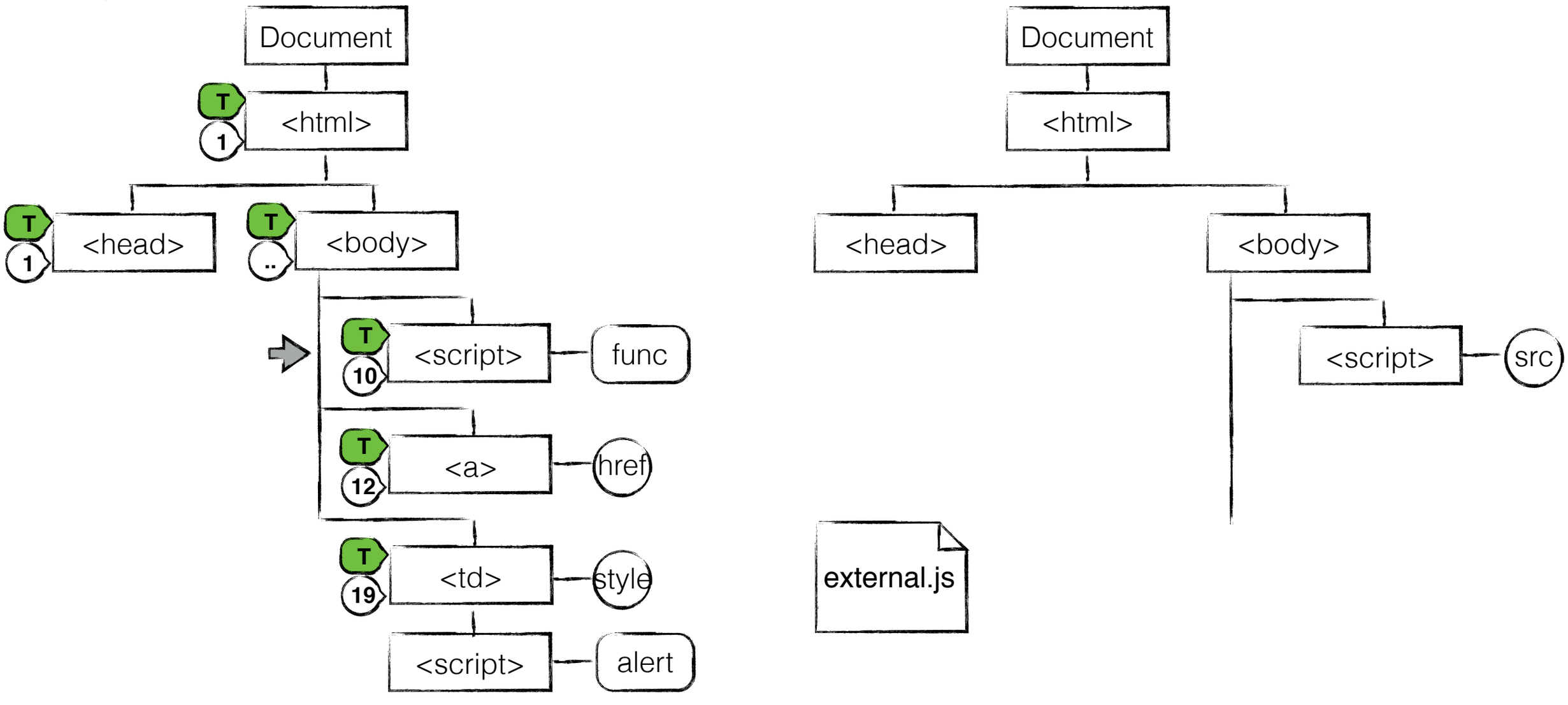
Content-Security-Policy: default-src ‘none’, script-src ‘self'



Edit Set | e_script_10 | | | |

(3) CSP Analysis

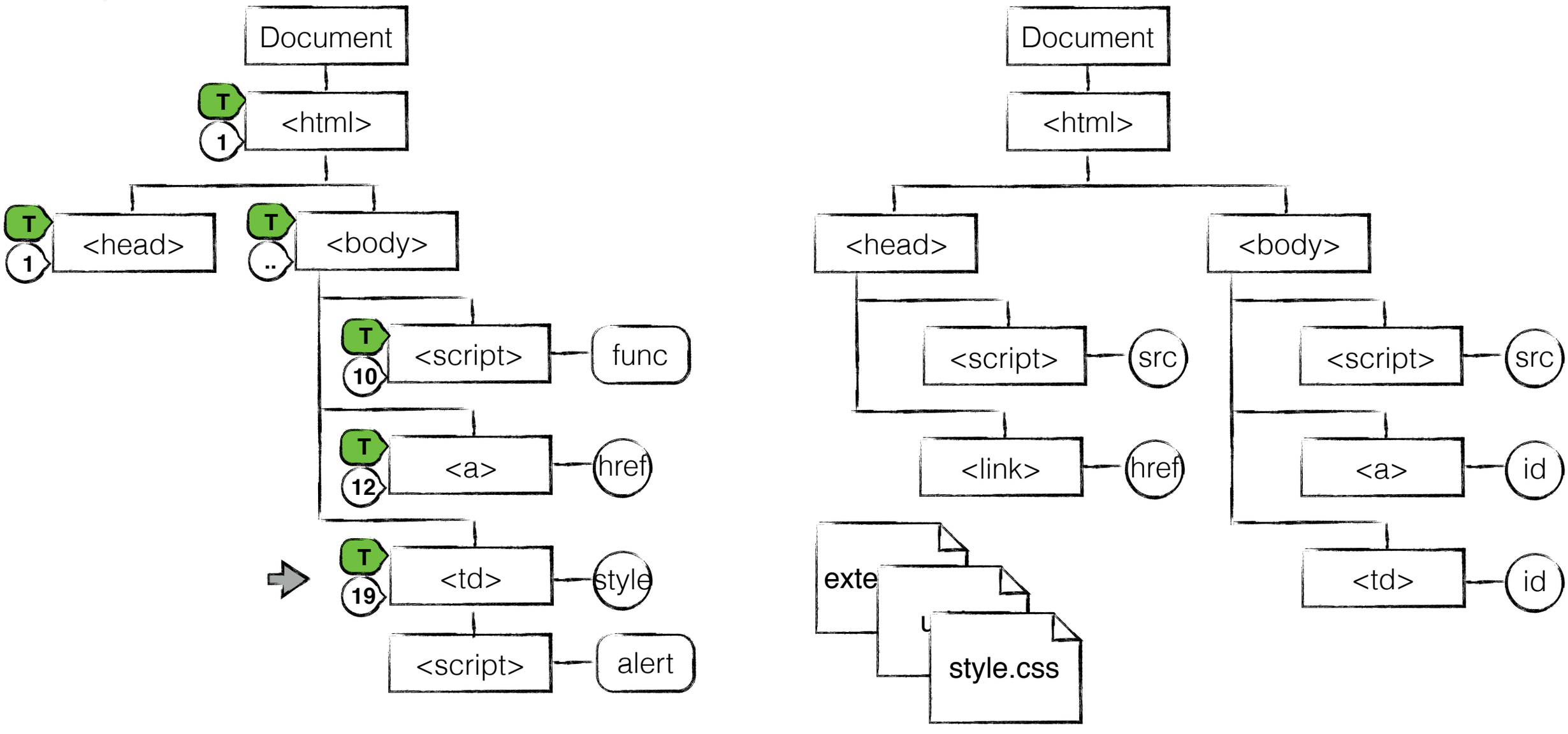
Content-Security-Policy: default-src ‘none’, script-src ‘self’; style-src ‘self’



Edit Set | e_script_10 | | | |

(3) CSP Analysis

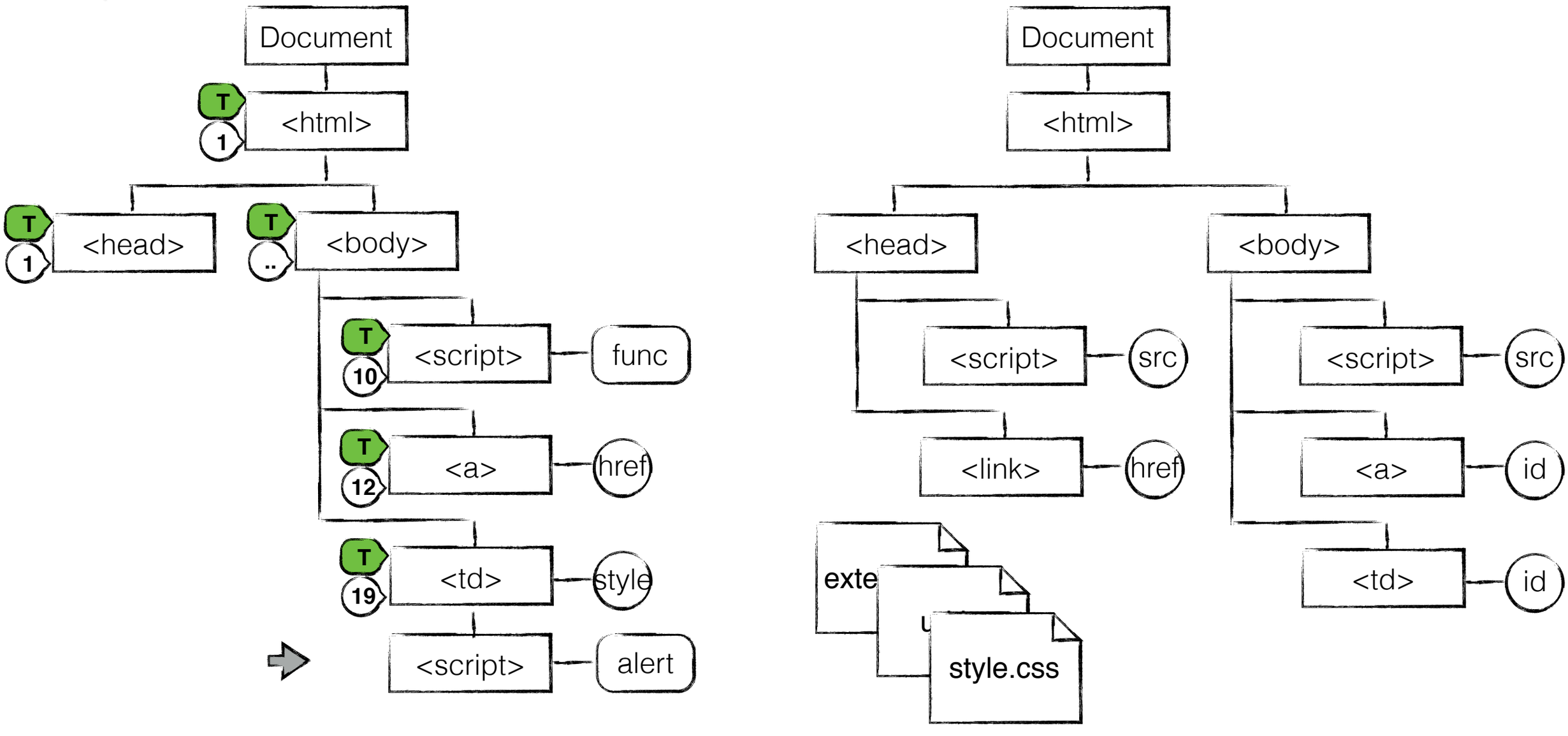
Content-Security-Policy: default-src ‘none’, script-src ‘self’; style-src ‘self’



Edit Set	e_script_10	e_a_12	e_td_19	

(3) CSP Analysis

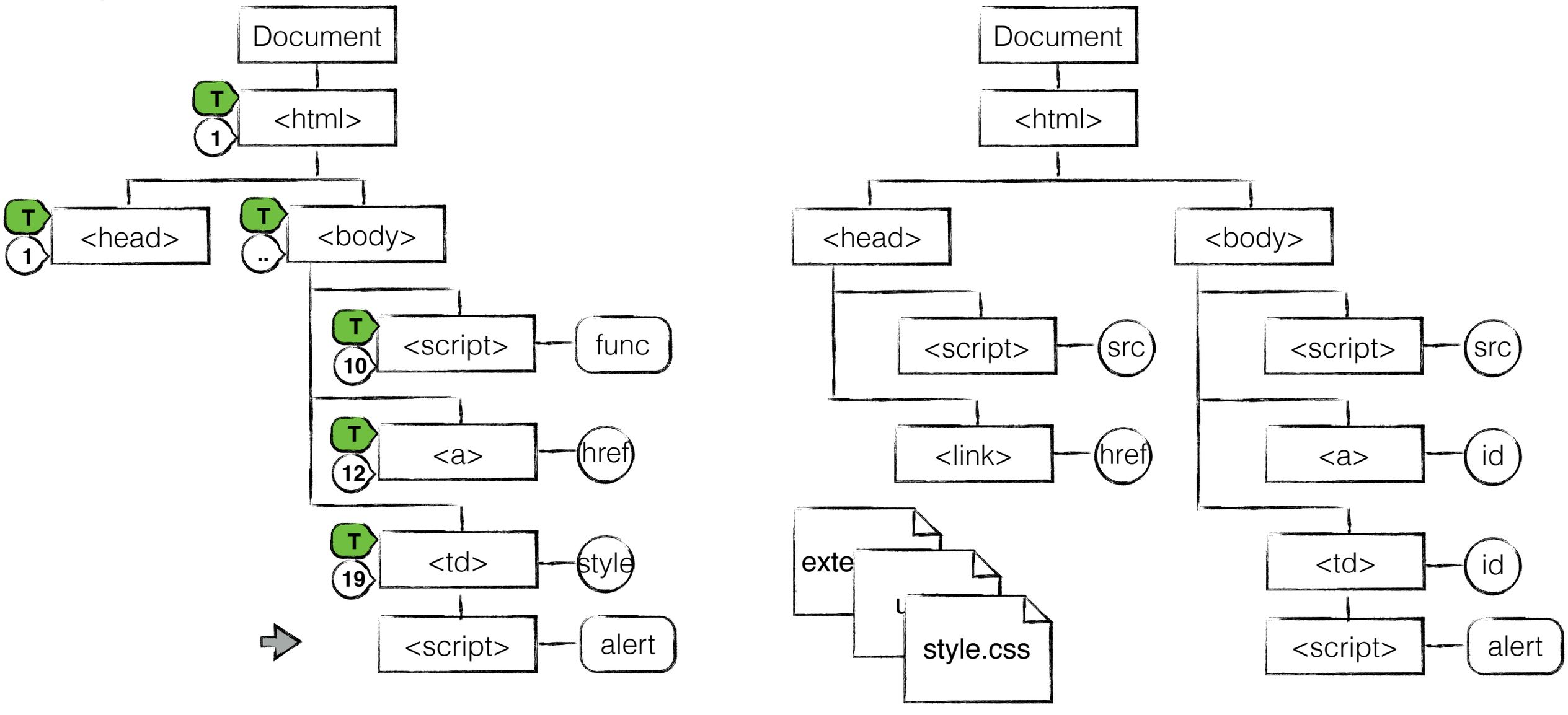
Content-Security-Policy: default-src ‘none’, script-src ‘self’; style-src ‘self’



Edit Set	e_script_10	e_a_12	e_td_19	

(3) CSP Analysis

Content-Security-Policy: default-src ‘none’, script-src ‘self’; style-src ‘self’



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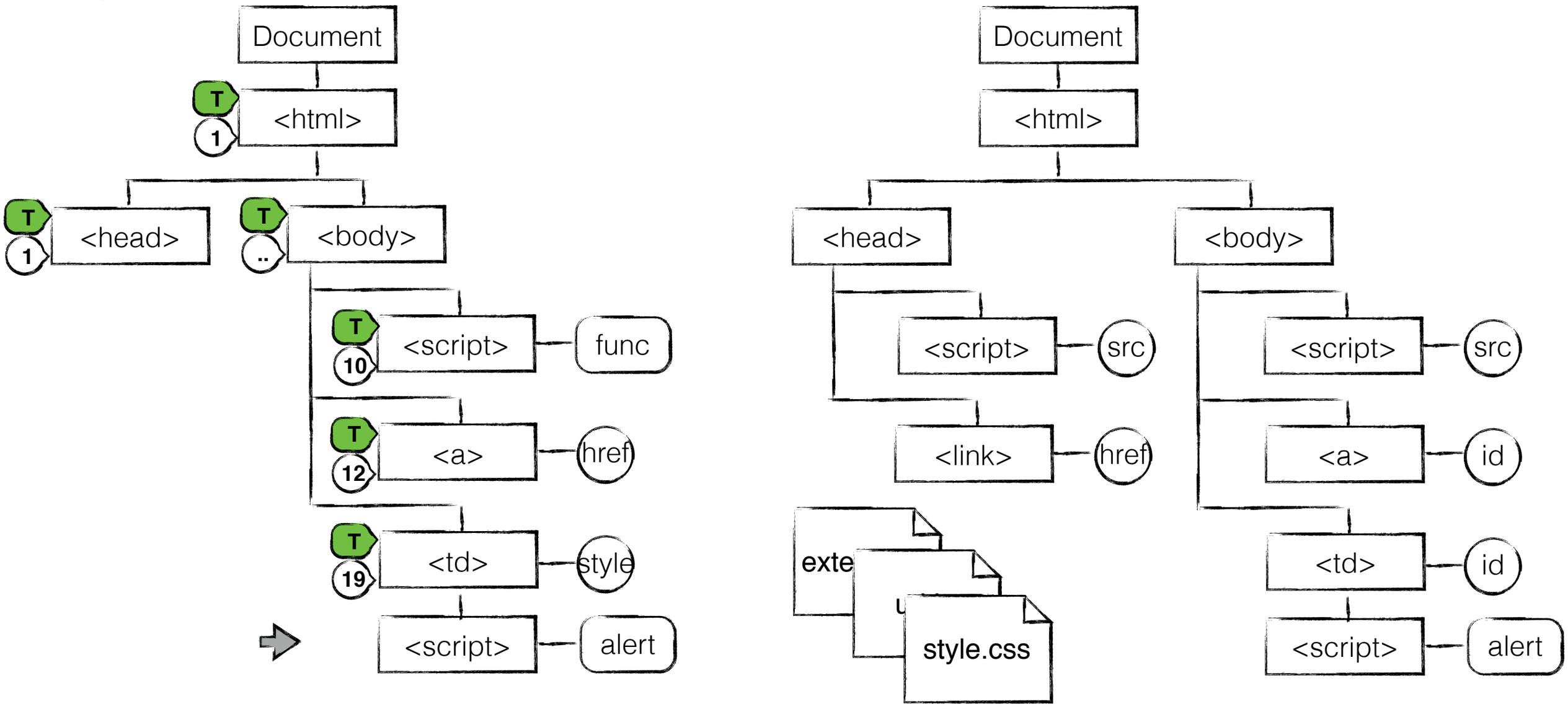

Edit Set	e_script_10	e_a_12	e_td_19	e_csp_1

(4) Source Code Transformation

Edit Set	e_script_10	e_a_12	e_td_19	e_csp_1

```
1 <?php print(“<html>\n <head>”);
2 ...
3 $out="<script>
4  function grades(){
5    document.student.page2.value=3;
6    document.student.submit();
7  }
8  </script>"
 9 ...
10 print($out);
11 ...
12 print("<a
13  href='javascript:grades();'>
14  Grades</a>");
15 ...
16 while($assignment =
17  mysql_fetch_row($query)){
18   ...
19   print("<td style='text-align:left;'>"
20    .$assignment[5].
21    "</td>");
22  ...
23  }
24 print("</html>"); ?>
```

(4) Source Code Transformation

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```

```
function filter_script_10($out){




}
```

(4) Source Code Transformation

Edit Set	e_script_10	e_a_12	e_td_19	e_csp_1

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1 <?php print(“<html>\n <head>”);
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```
function filter_script_10($out){

 $newOut=$out;

 $newScript="<script>function grades(){..}</script>";

 $newScript=str_replace("<script>function grades(){..}</script>",
  "<script src='external.js'></script>",
  $newScript);









}
```

(4) Source Code Transformation

Edit Set	e_script_10	e_a_12	e_td_19	e_csp_1

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1 <?php print(“<html>\n <head>”);
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 $newOut=$out;

 $newScript="<script>function grades(){..}</script>";

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  "<script src='external.js'></script>",
  $newScript);

 $newOut=str_replace("<script>function grades(){..}</script>",
  $newScript,
  $newOut);

 return $newOut;

}
```

(4) Source Code Transformation

Edit Set	e_script_10	e_a_12	e_td_19	e_csp_1

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Implementation

Dynamic Tainting

Web Page Analysis

CSP Analysis

Source Code Transformation

Implementation

Dynamic Tainting

Web Page Analysis

CSP Analysis

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Empirical Evaluation

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Subjects

Benchmark	*Type*	*Version*	*KLOC*
Gallery	Photo Sharing	1.5	34.5
LinPHA	Photo Sharing	1.3	59.6
MyBB	Forum	1.6	105.9
OpenEMR	Medical Management	4.1	480
phpList	Newsletter management	2.10	35.4
Schoolmate	School Management	1.5	6.5
Serendipity	Blogging	0.8	49.6

Subjects

Benchmark	*Type*	*Version*	*KLOC*	*MI*
Gallery	Photo Sharing	1.5	34.5	4
LinPHA	Photo Sharing	1.3	59.6	4
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phpList	Newsletter management	2.10	35.4	4
Schoolmate	School Management	1.5	6.5	4
Serendipity	Blogging	0.8	49.6	4

Malicious Inputs (MI)

CVE Details

OWASP

HTML5 Security Cheatsheet

Subjects

Benchmark	*Type*	*Version*	*KLOC*	*MI*	*I*
Gallery	Photo Sharing	1.5	34.5	4	16
LinPHA	Photo Sharing	1.3	59.6	4	43
MyBB	Forum	1.6	105.9	4	63
OpenEMR	Medical Management	4.1	480	4	113
phpList	Newsletter management	2.10	35.4	4	77
Schoolmate	School Management	1.5	6.5	4	90
Serendipity	Blogging	0.8	49.6	4	65

Malicious Inputs (MI)

CVE Details

HTML5 Security Cheatsheet

Inputs (I)

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Attacks Blocked

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RQ1(2)

RQ1(2): Can AutoCSP retrofit CSP to web applications and offer an effective protection against XSS attacks **without disrupting the applications' functionality?**

Benchmark	*Inputs*	*None*	*Self*	*AutoCSP*
Gallery	16	175	68	0
LinPHA	43	231	136	0
MyBB	63	598	364	2
OpenEMR	113	699	533	11
phpList	77	1224	273	1
Schoolmate	90	16	8	0
Serendipity	65	476	385	6

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E1: client-side execution of eval. `var x = eval('...');`

E2: client-side creation on inline script nodes. `document.write('<script>...</script>');`

E3: client-side creation on inline style nodes. `document.write('<style>...</style>');`

RQ4

RQ4: Is automation actually needed to retrofit CSP to web applications?

Benchmark	E_{csp}	E_e	F
Gallery	2	76	12
LinPHA	2	67	11
MyBB	5	97	6
OpenEMR	31	319	52
phpList	1	33	8
Schoolmate	1	328	26
Serendipity	5	103	16

RQ4

RQ4: Is automation actually needed to retrofit CSP to web applications?

Benchmark	E_{csp}	E_e	F
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Serendipity	5	103	16

E_{csp}*:* number of CSP edits.

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E_{csp}*:* number of CSP edits.

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E_{csp}*:* number of CSP edits.

E_e*:* number of modified HTML elements.

E_{csp}*:* number of modified files.

Evaluation Summary

RQ1: Can AutoCSP retrofit CSP to web applications and offer an effective protection against XSS attacks without disrupting the applications' functionality?

AutoCSP offers effective protection against XSS.

AutoCSP introduces low number of false alarms.

RQ4: Is automation actually needed to retrofit CSP to web applications?

Automation is needed.

Related Work

Content Security Policy

Doupé et al., Stamm et al., and Weinberger et al.

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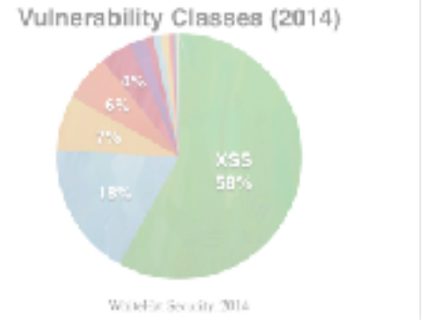
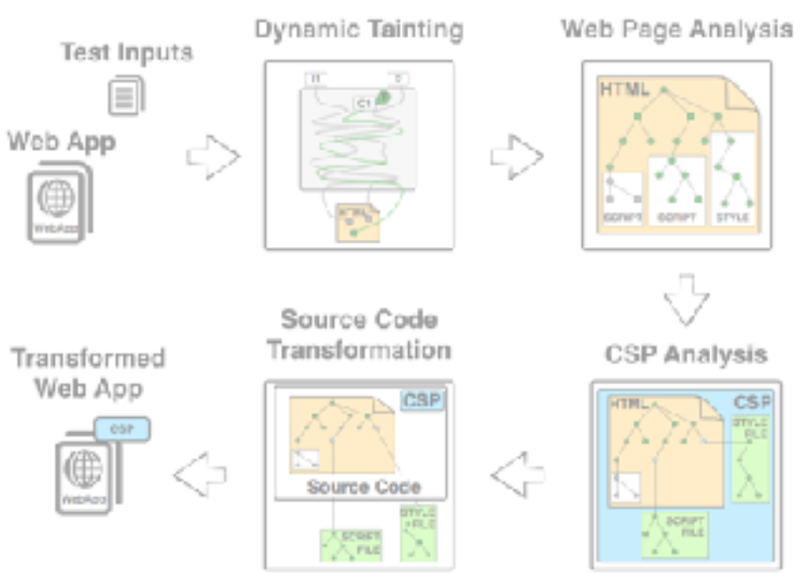


Content Security Policy (CSP)

AutoCSP



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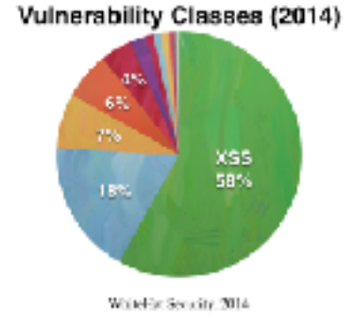

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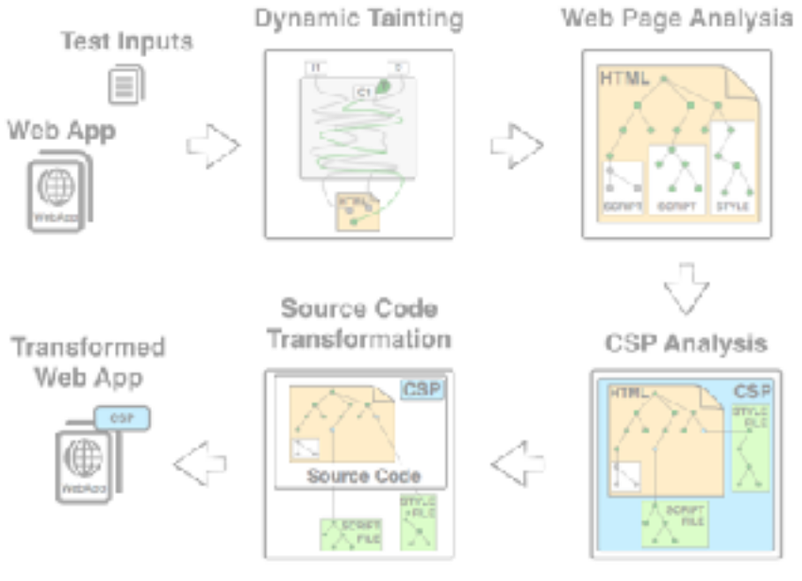

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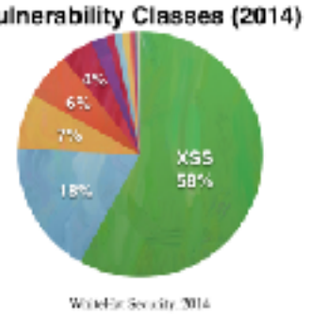

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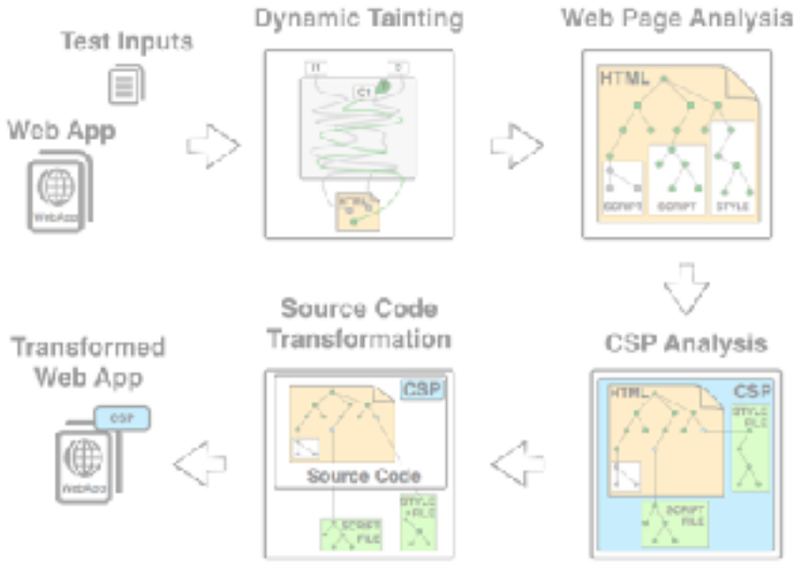

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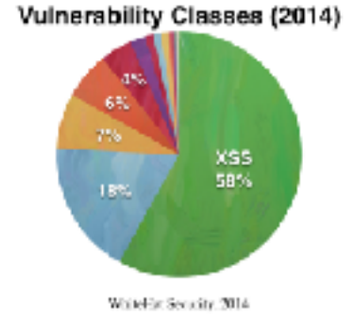
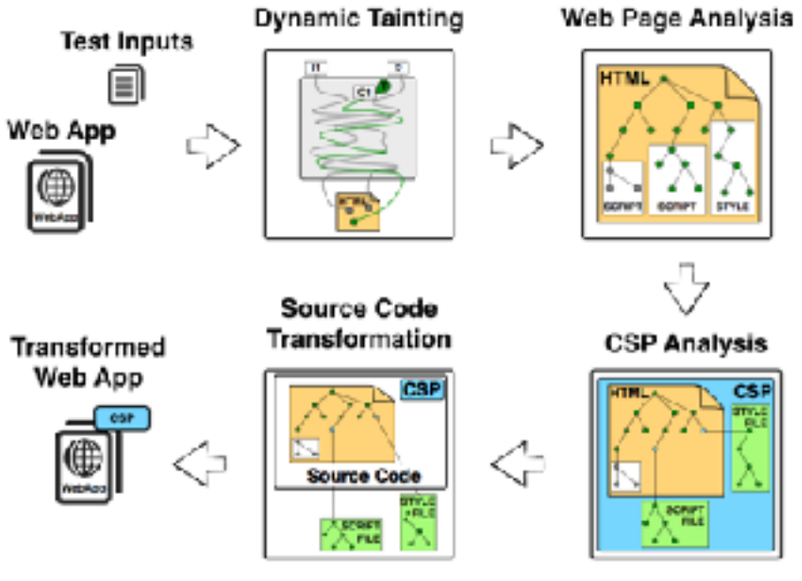


Content Security Policy (CSP)

AutoCSP



Empirical Evaluation

Research Questions:

RQ1: Can AutoCSP retrofit CSP to web applications and offer an effective protection against XSS attacks without disrupting the applications' functionality?

RQ2: What is the effect of AutoCSP on the performance of the retrofitted web applications?

RQ3: How dependent is AutoCSP's performance on the input used for its taint analysis?

RQ4: Is automation actually needed to retrofit CSP to web applications?

Summary

Cross-Site Scripting (XSS)

18 Sep 2014
"eBay Under Fire After Cross Site Scripting Attack"

16 Sep 2013
"NASDAQ Website Vulnerable to XSS Attacks"

28 May 2013
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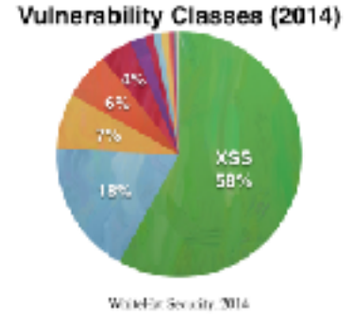

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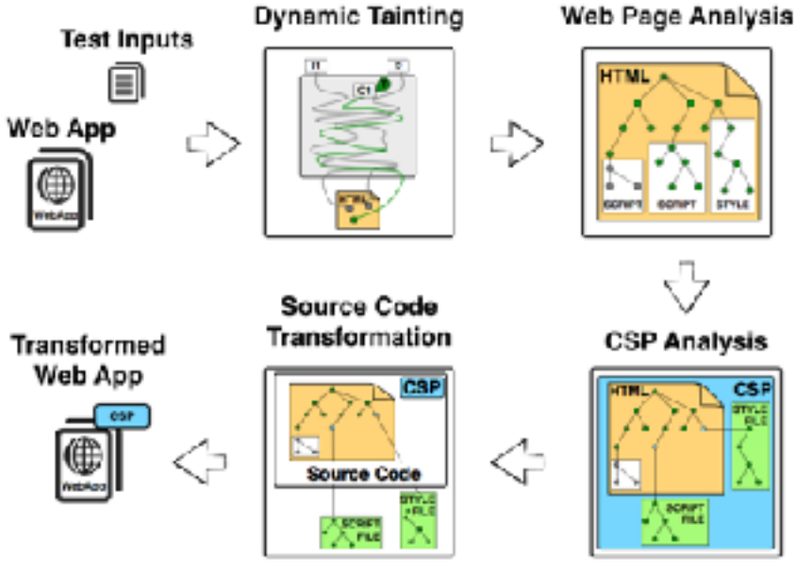

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